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29/808-29/8083; H01L 2924/13062

See application file for complete search history.

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### Related U.S. Application Data

(60) Provisional application No. 61/831,906, filed on Jun. 6, 2013, provisional application No. 61/833,217, filed on Jun. 10, 2013.

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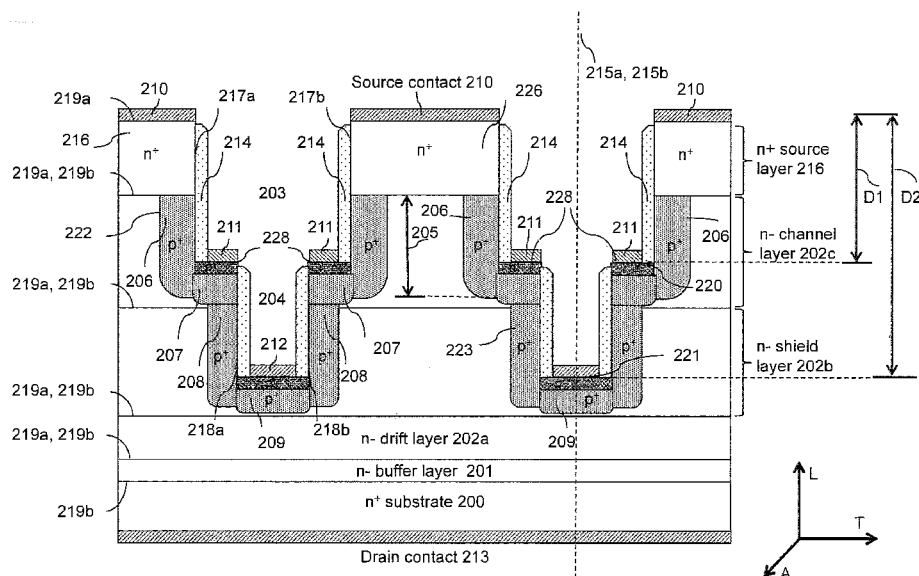
(51) **Int. Cl.**  
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*H01L 29/66* (2006.01)  
*H01L 29/06* (2006.01)  
*H01L 29/10* (2006.01)

(52) **U.S. Cl.**  
CPC ..... *H01L 29/083* (2013.01); *H01L 29/0619*  
(2013.01); *H01L 29/1066* (2013.01); *H01L*  
*29/66909* (2013.01); *H01L 2924/13062*  
(2013.01)

(57) **ABSTRACT**

A shielded junction field effect transistor (JFET) is described having gate trenches and shield trenches, the shield trenches being deeper and narrower than the gate trenches. The gate trenches may be fully aligned, partially aligned, or separated from the shield trenches.

**23 Claims, 35 Drawing Sheets**



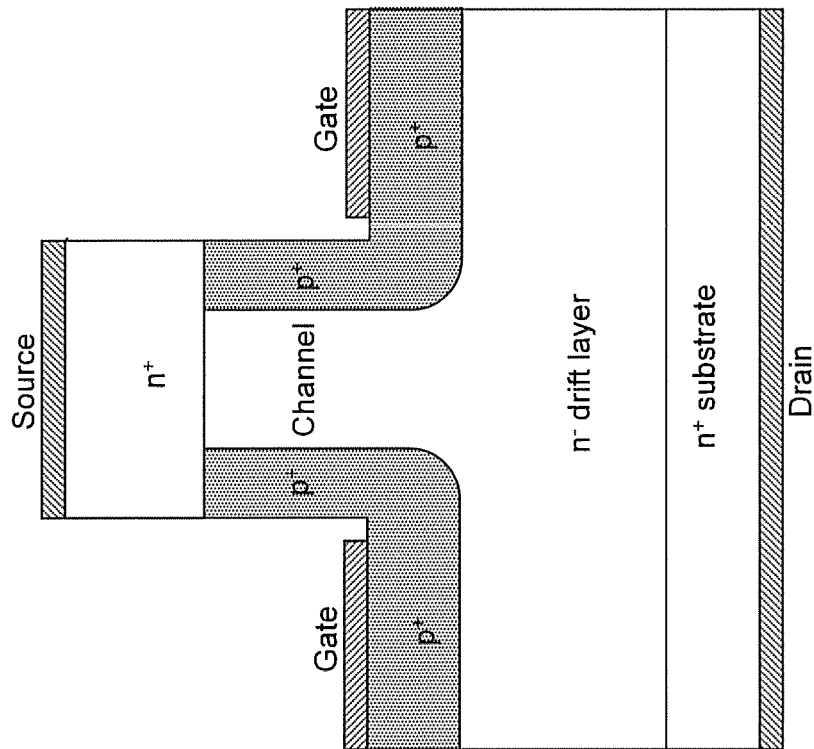


FIGURE 1A

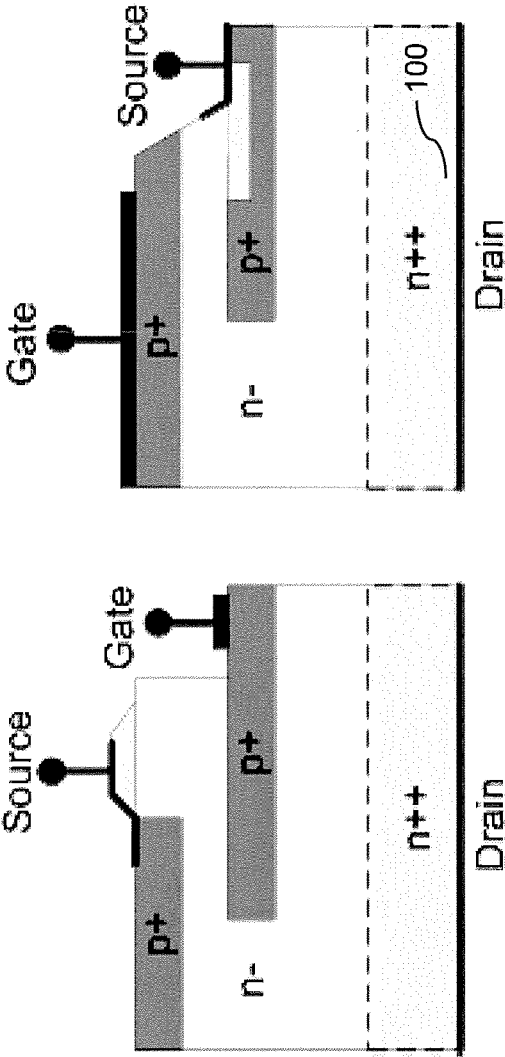


FIGURE 1B

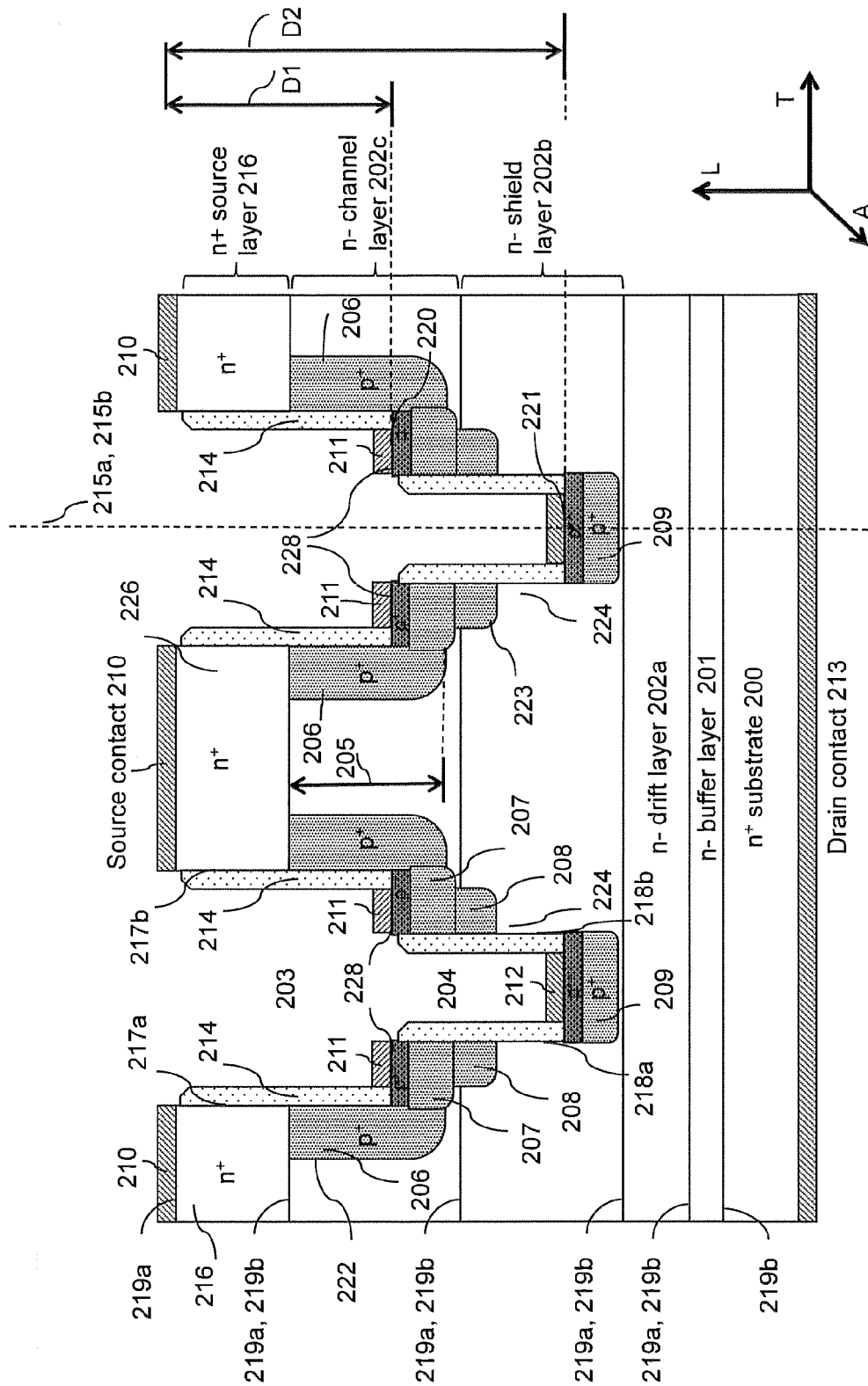


FIGURE 2A

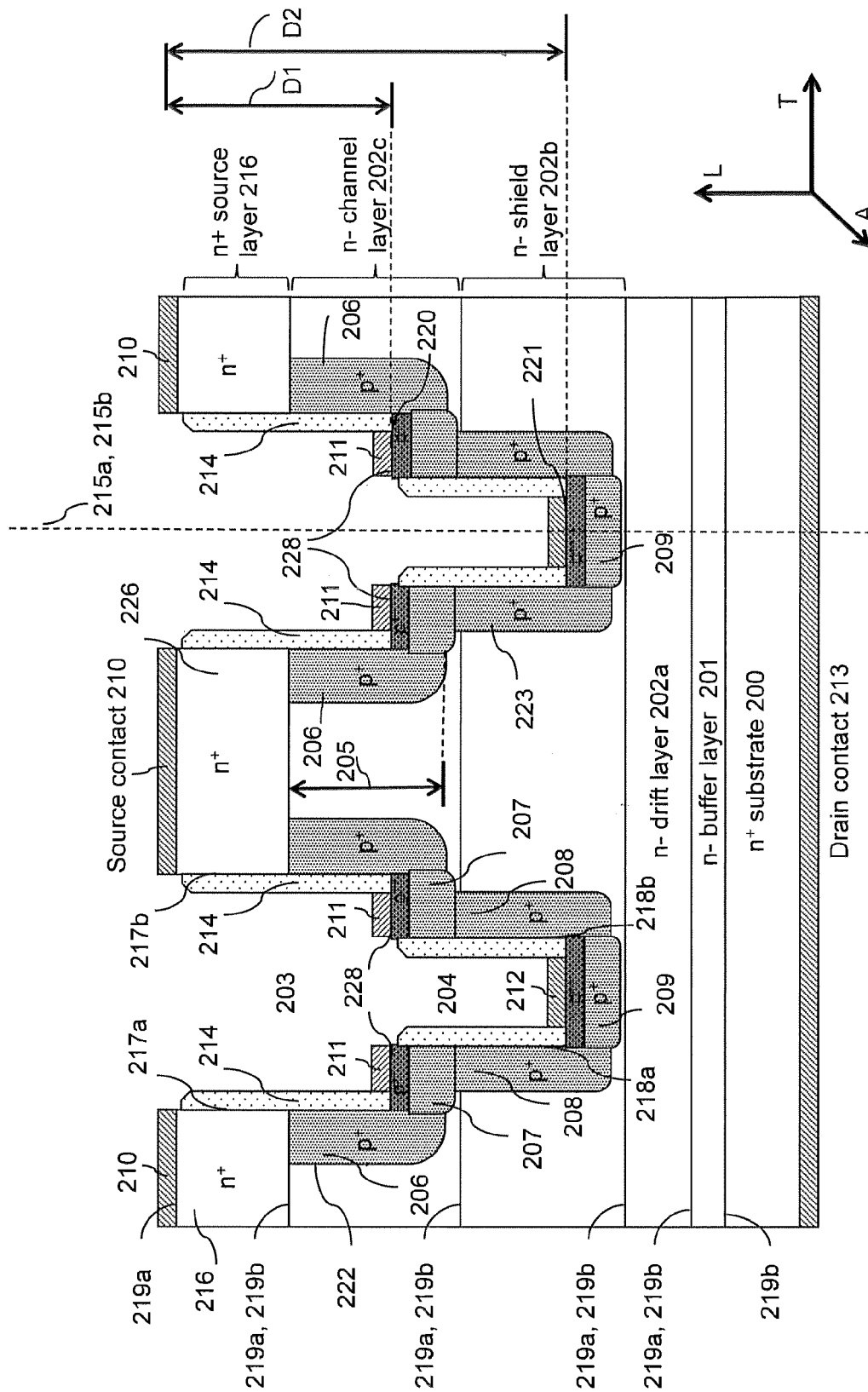
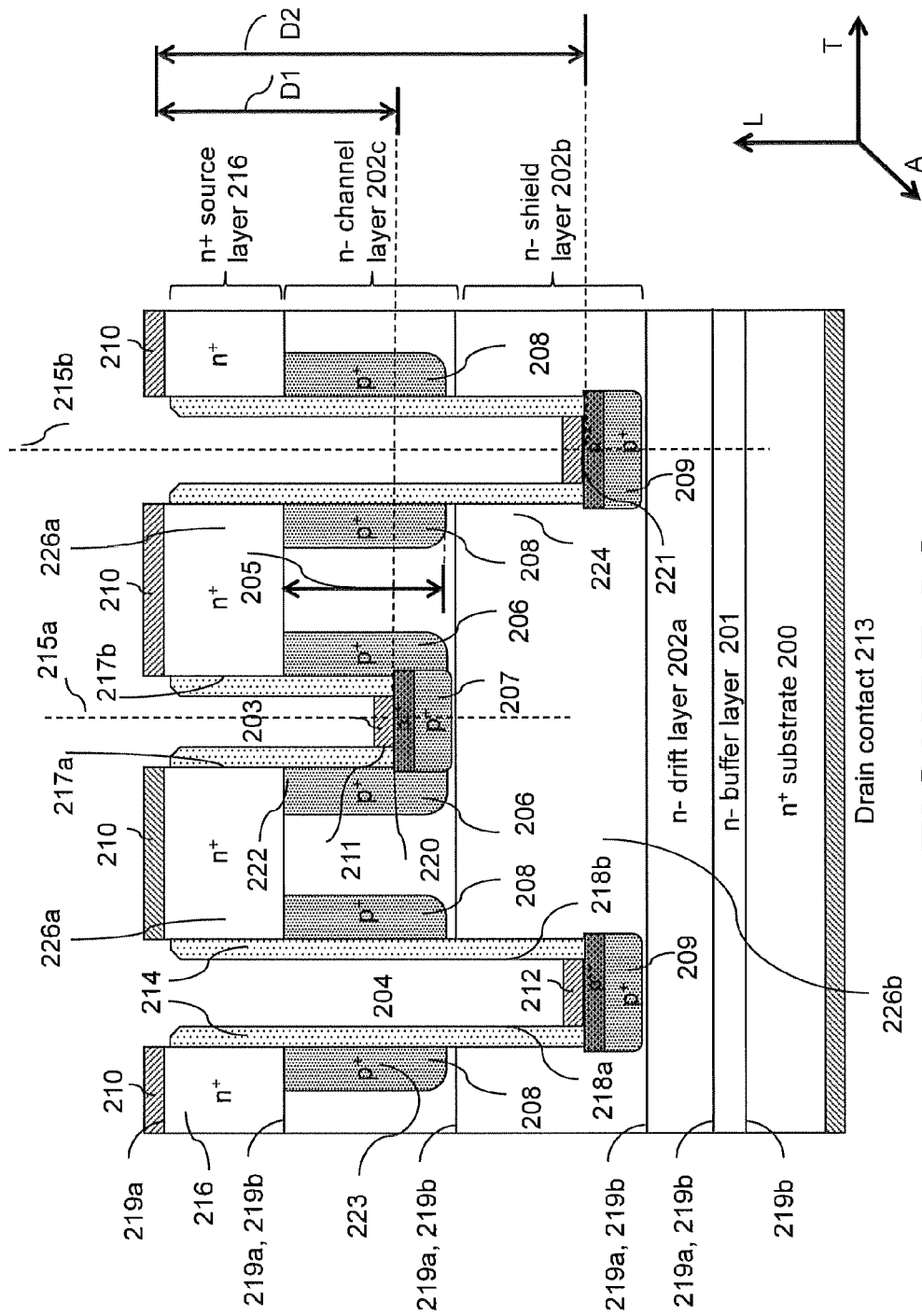


FIGURE 2B



## FIGURE 2C

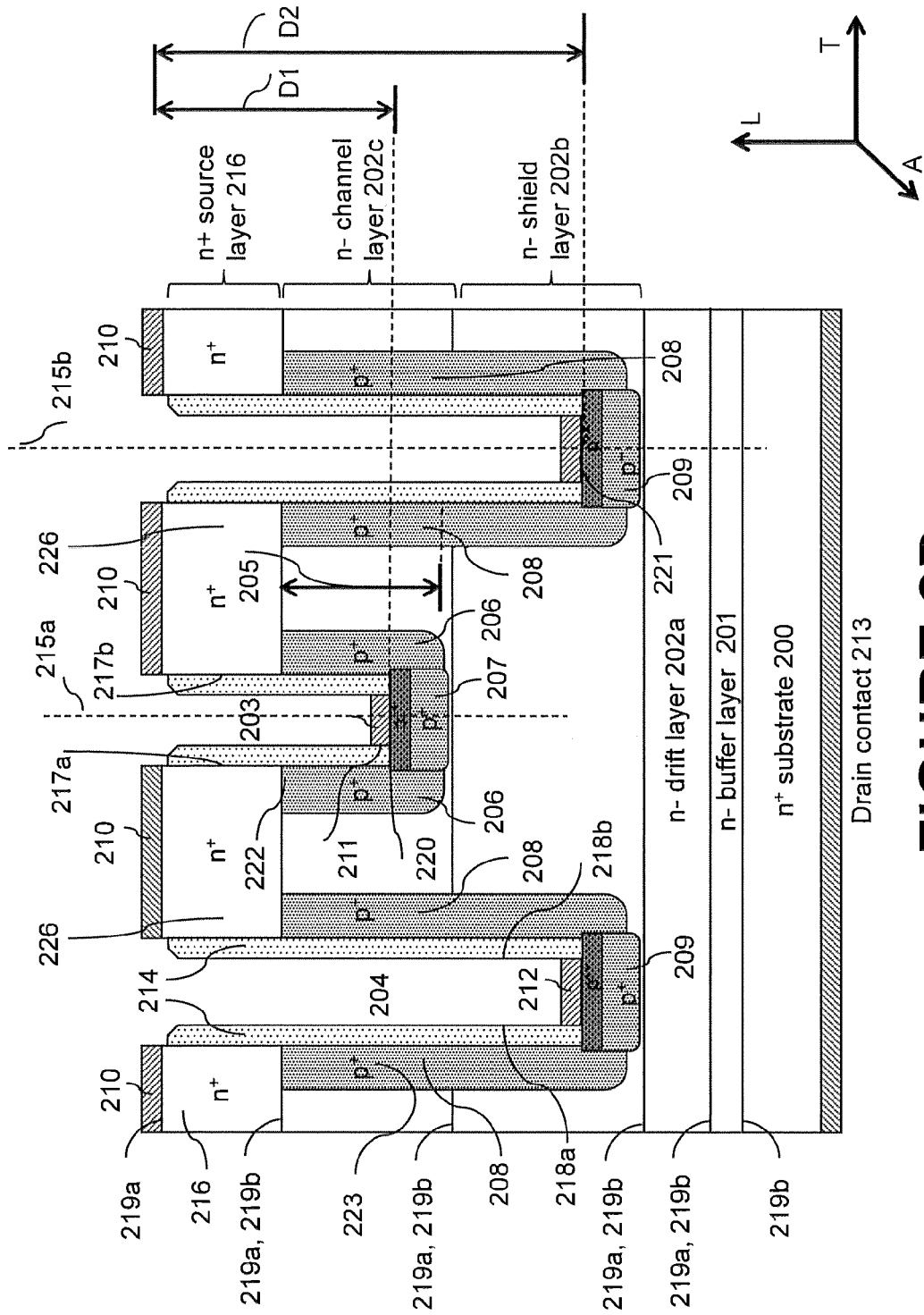
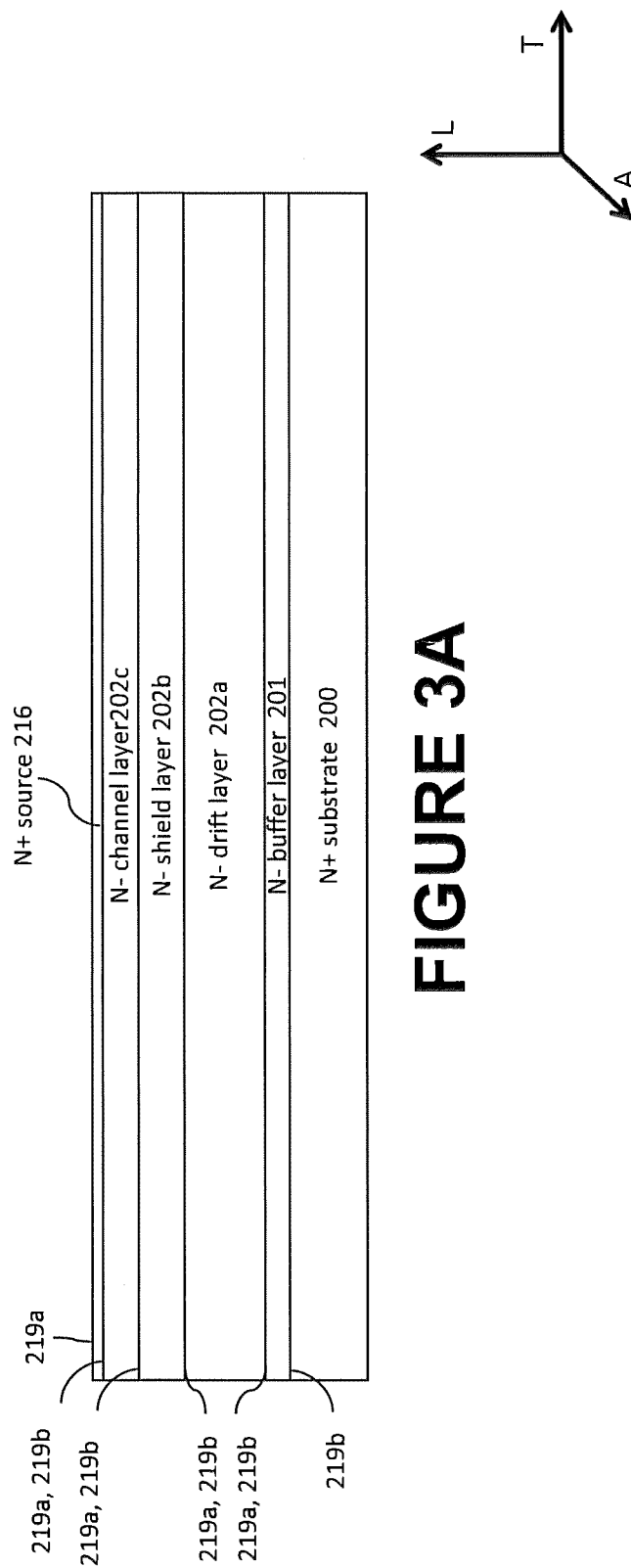


FIGURE 2D



# FIGURE 3A



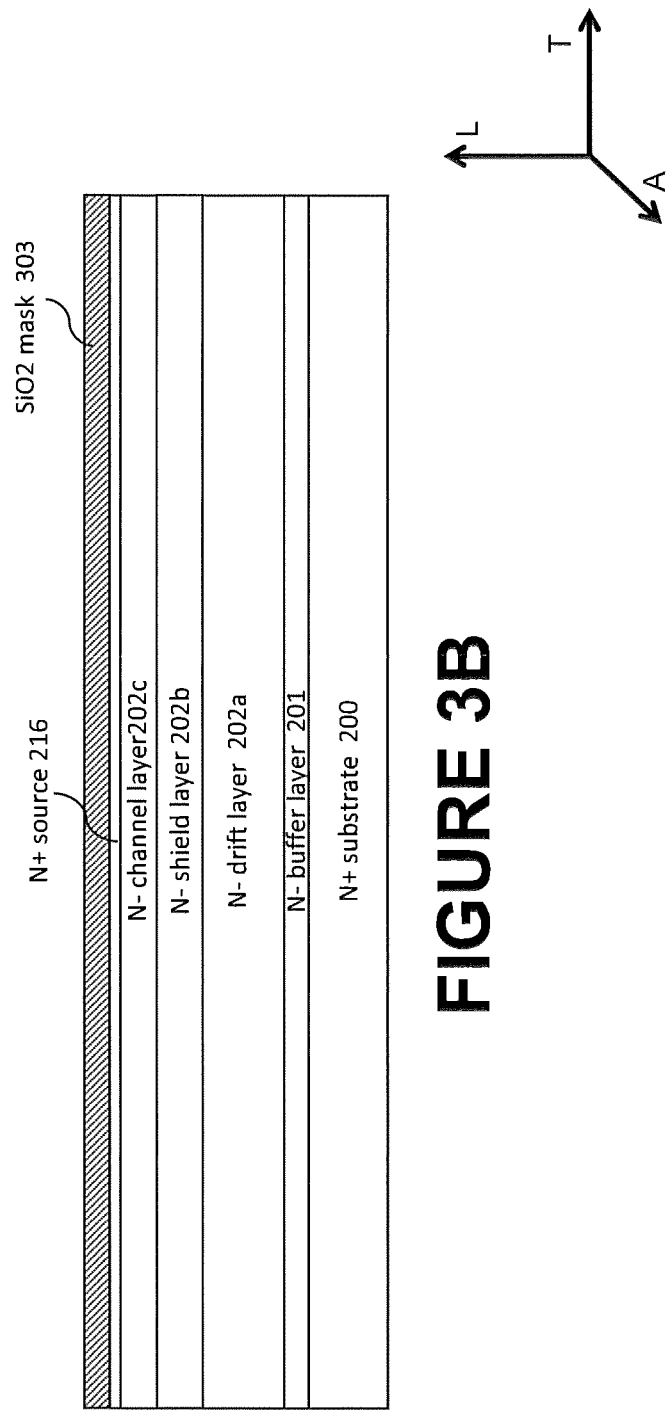


FIGURE 3B

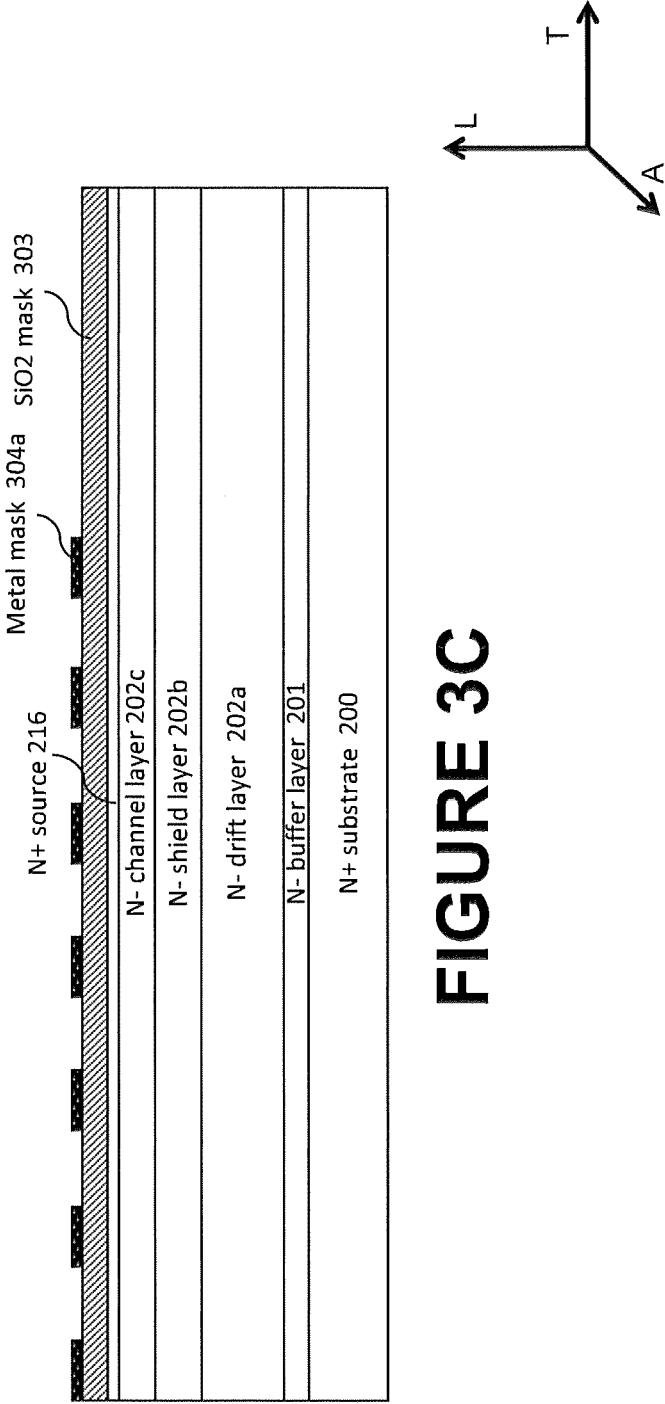
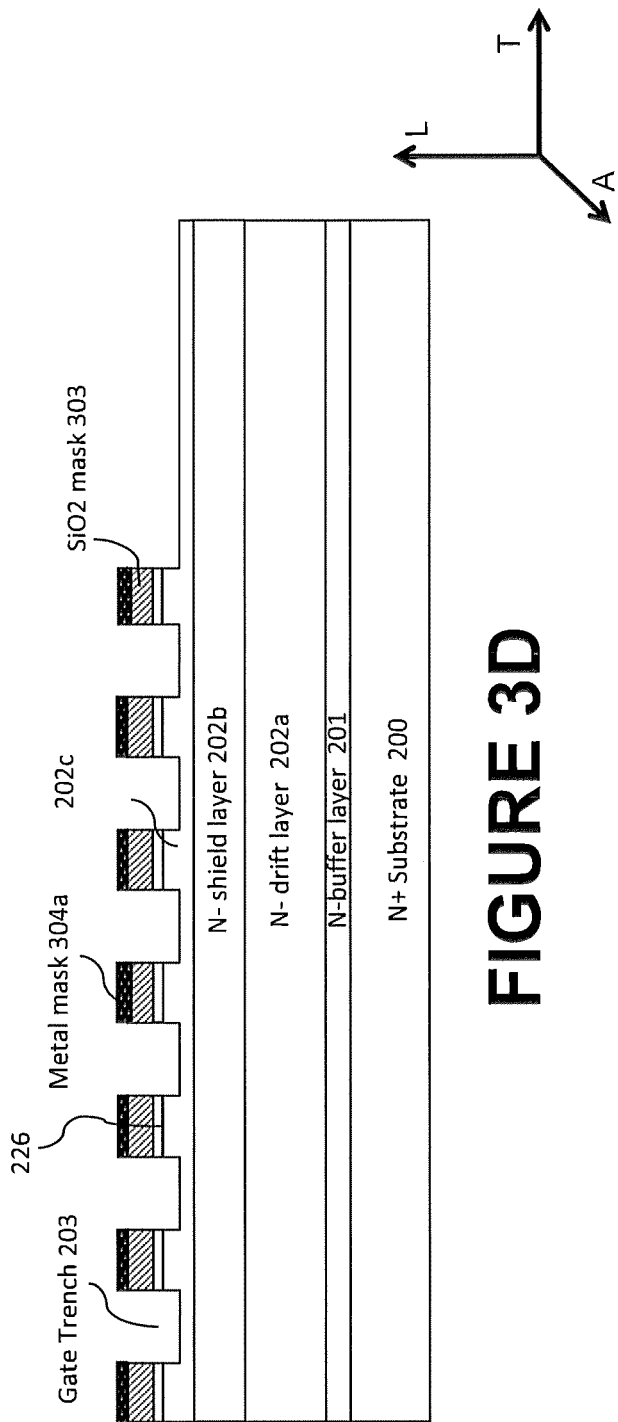


FIGURE 3C



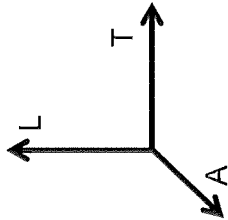
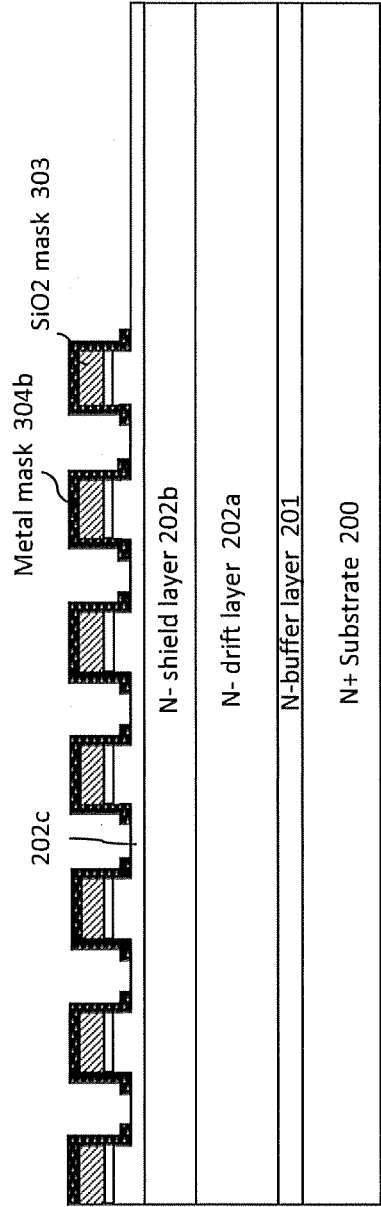
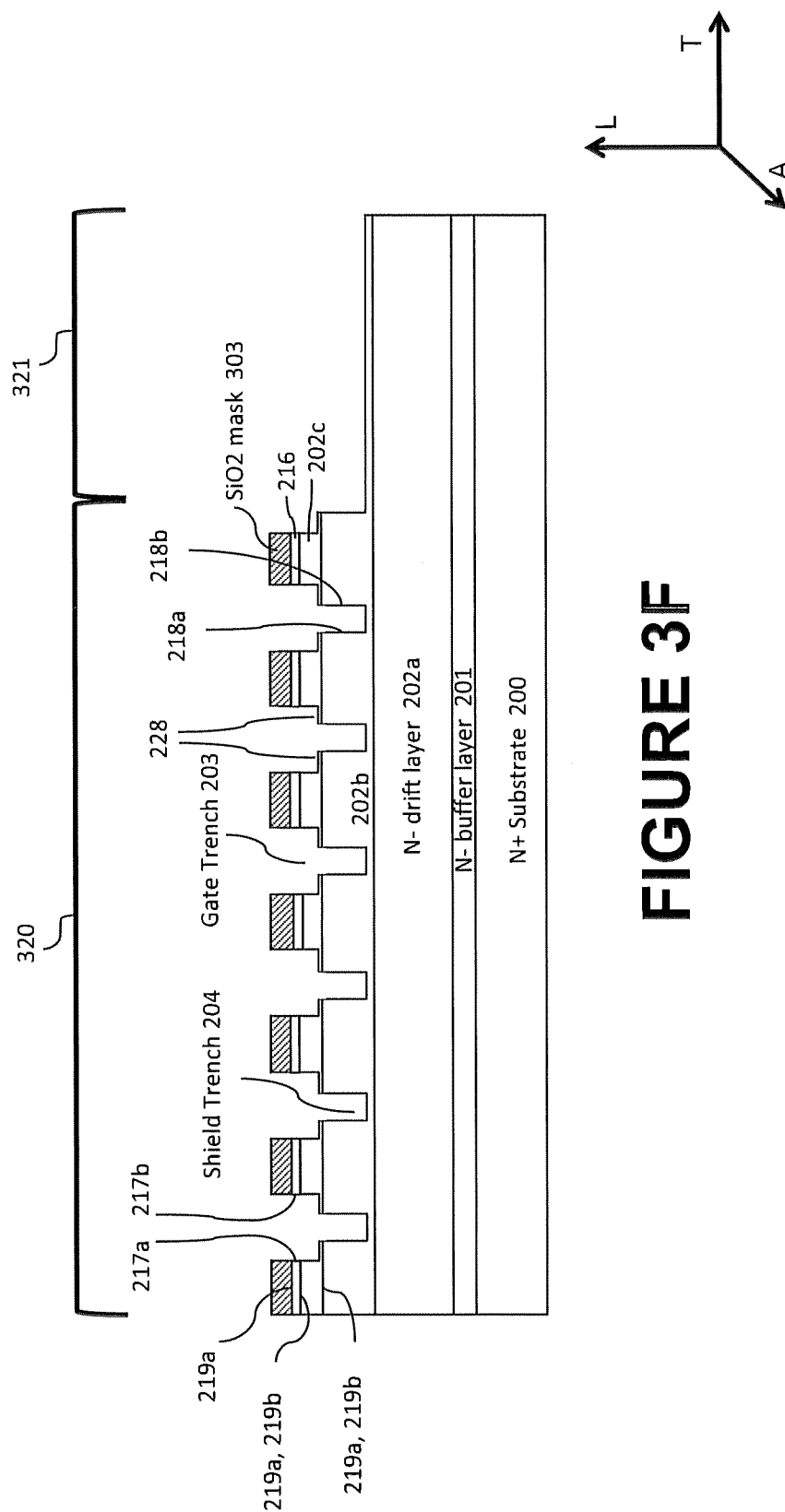
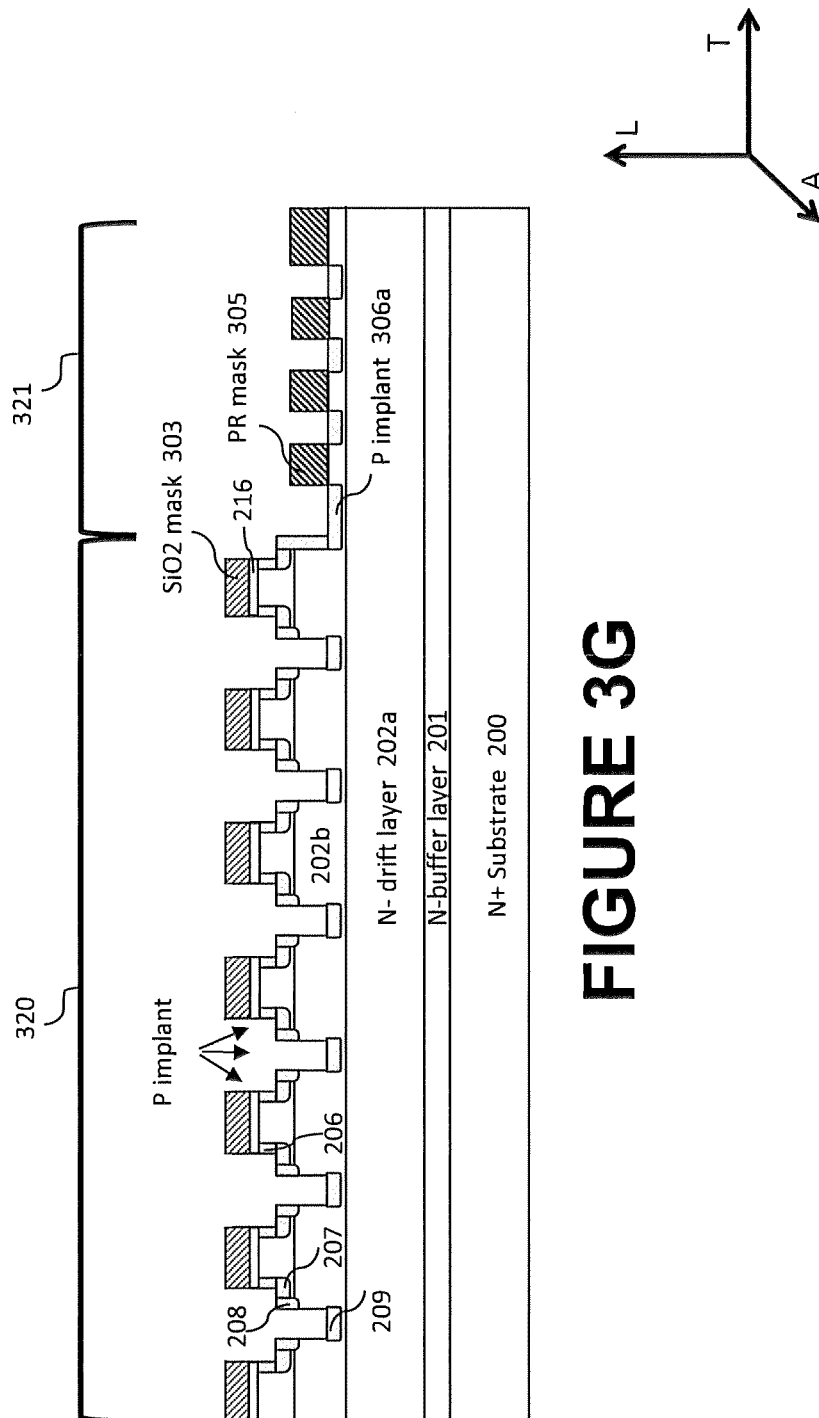


FIGURE 3E



# FIGURE 3F



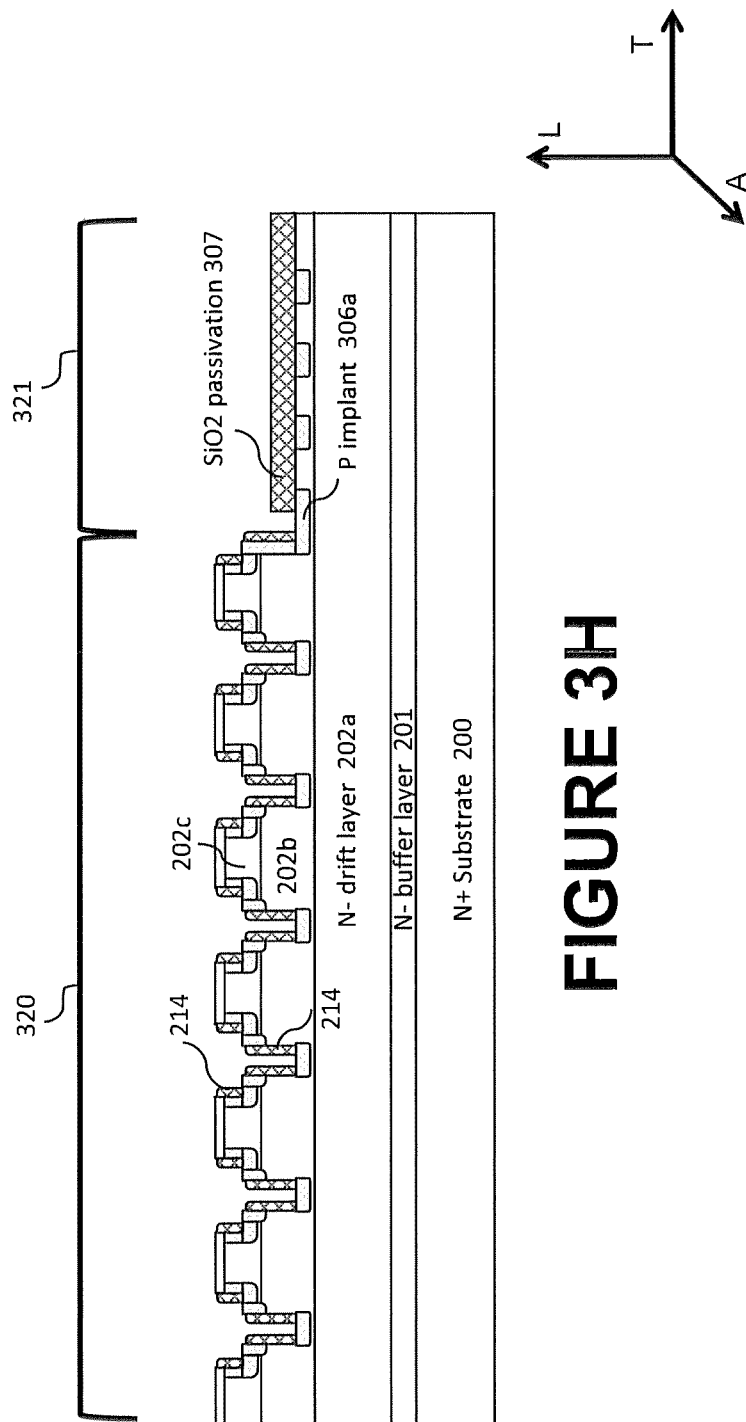


FIGURE 3H

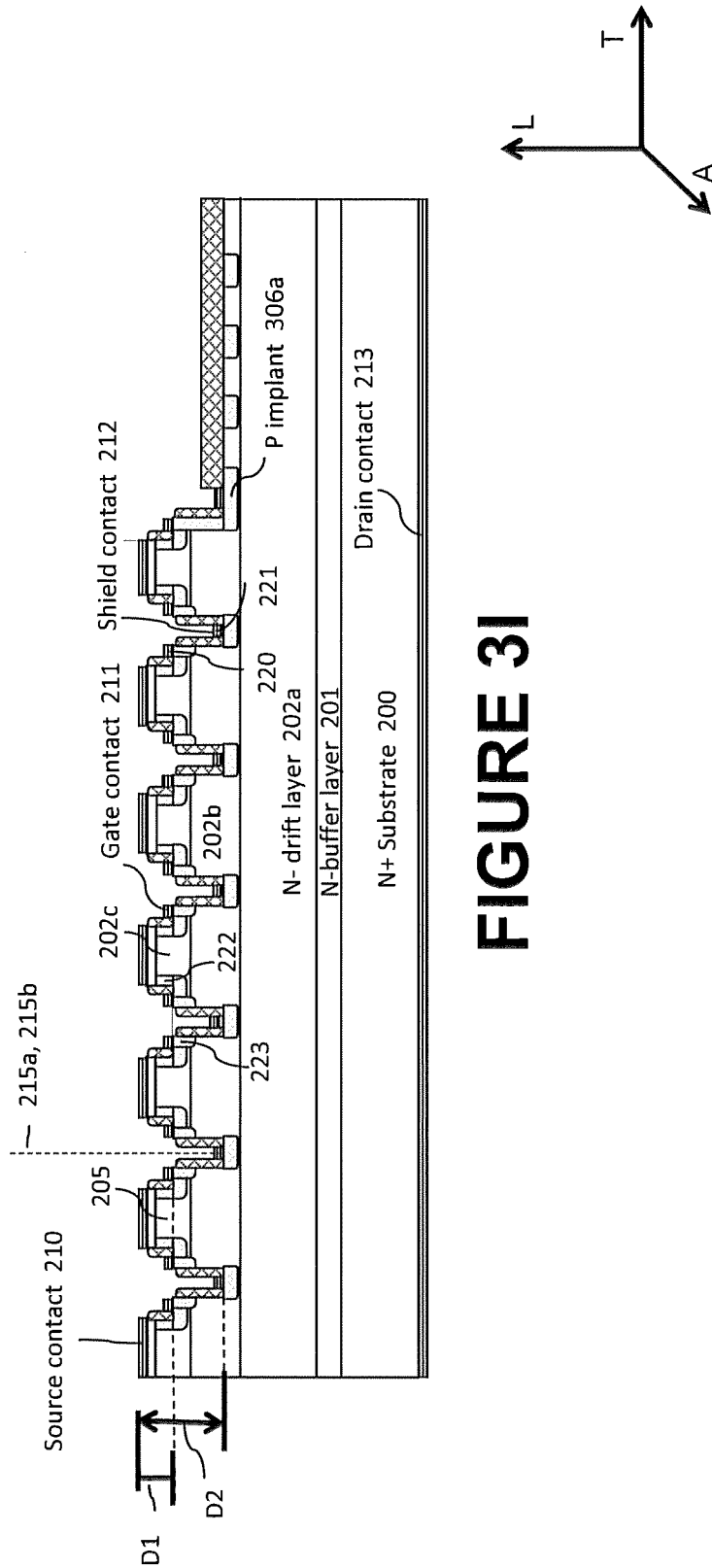
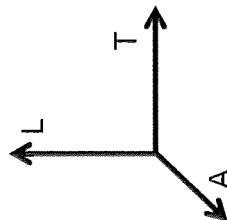
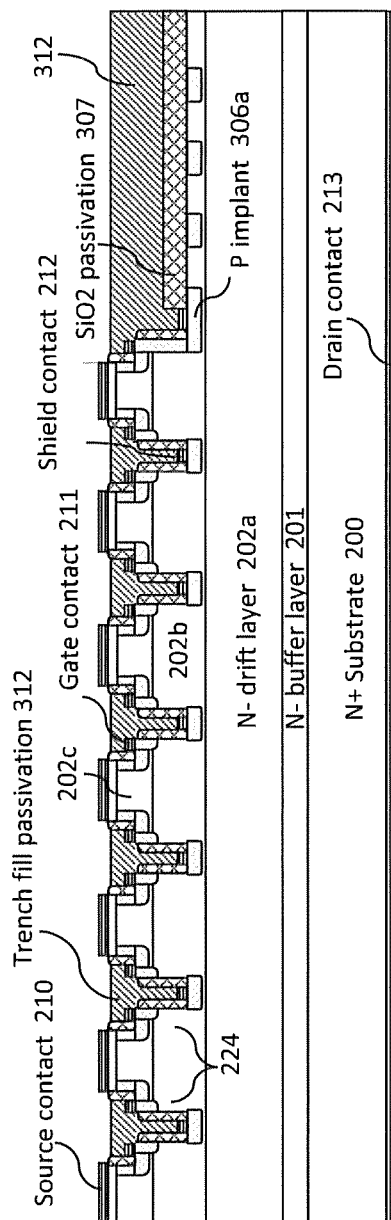
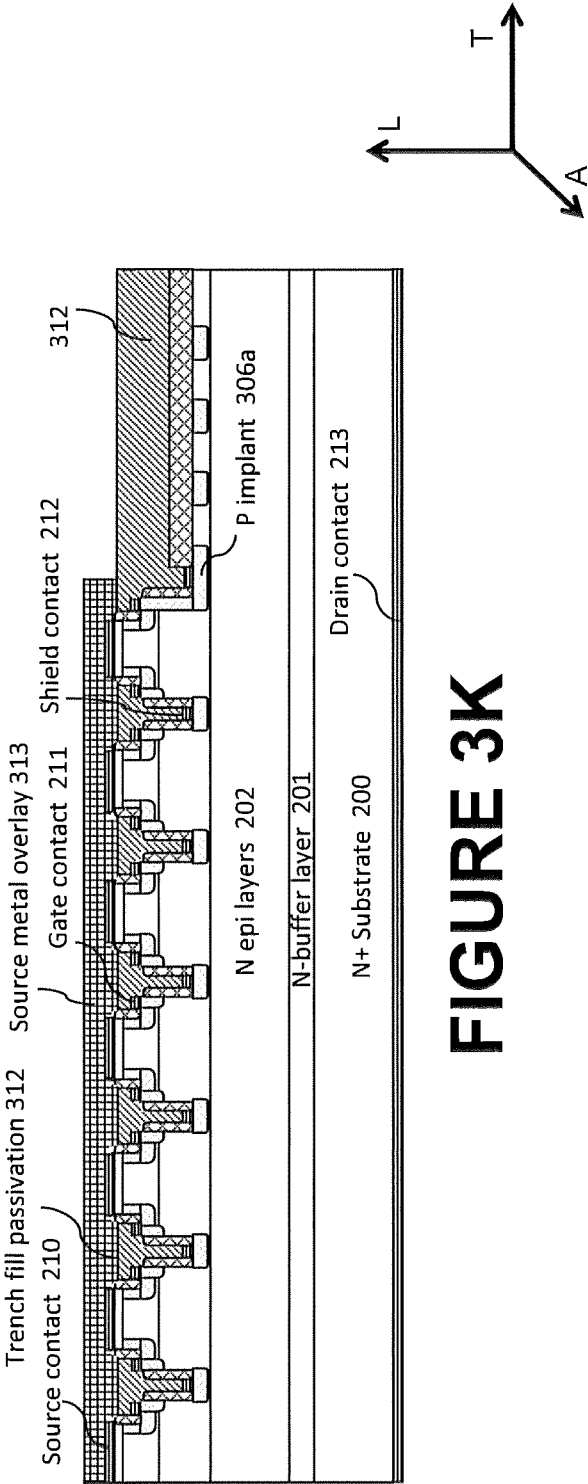


FIGURE 3I





# FIGURE 3J



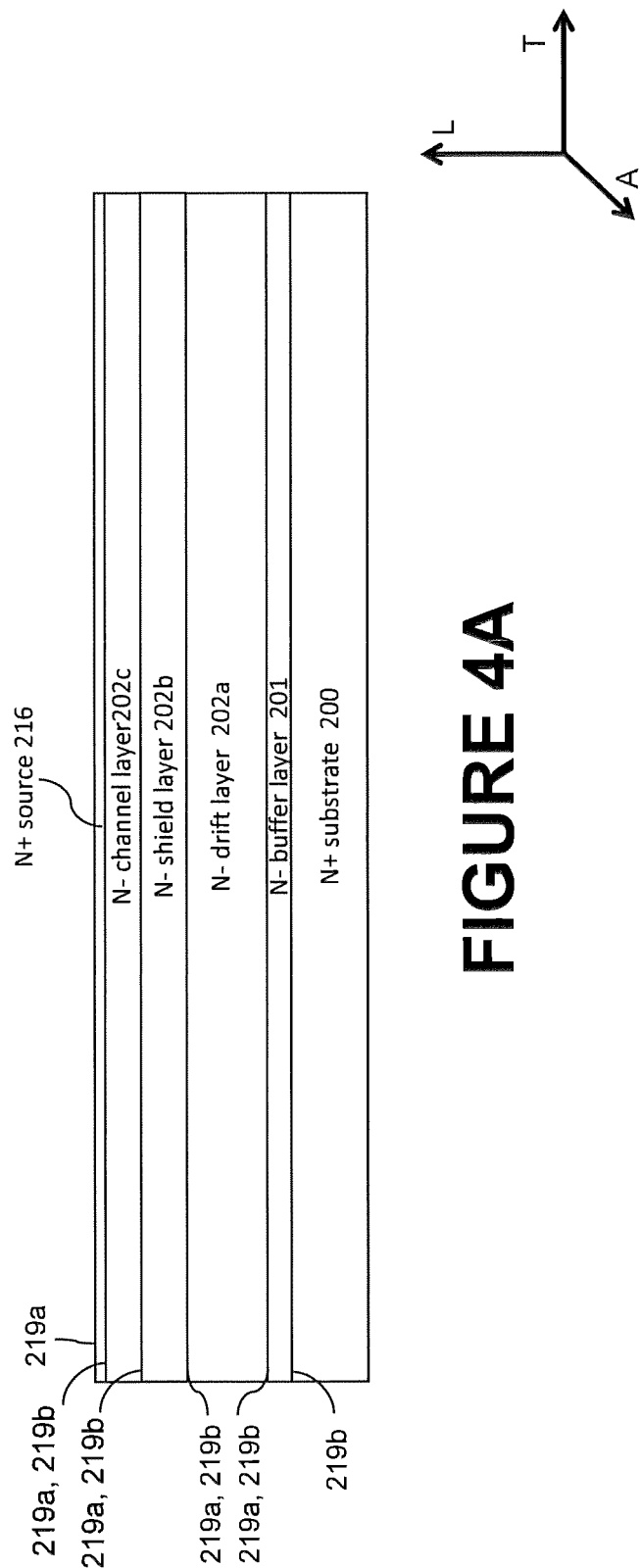


FIGURE 4A

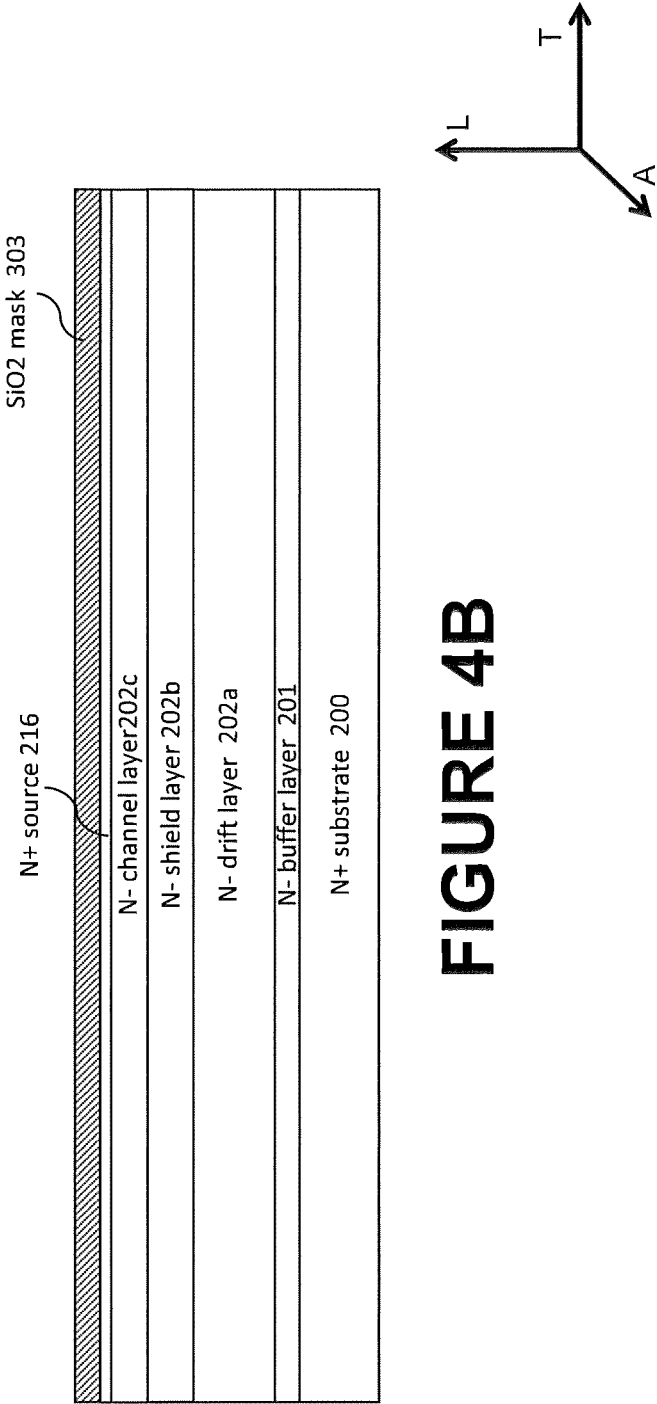


FIGURE 4B

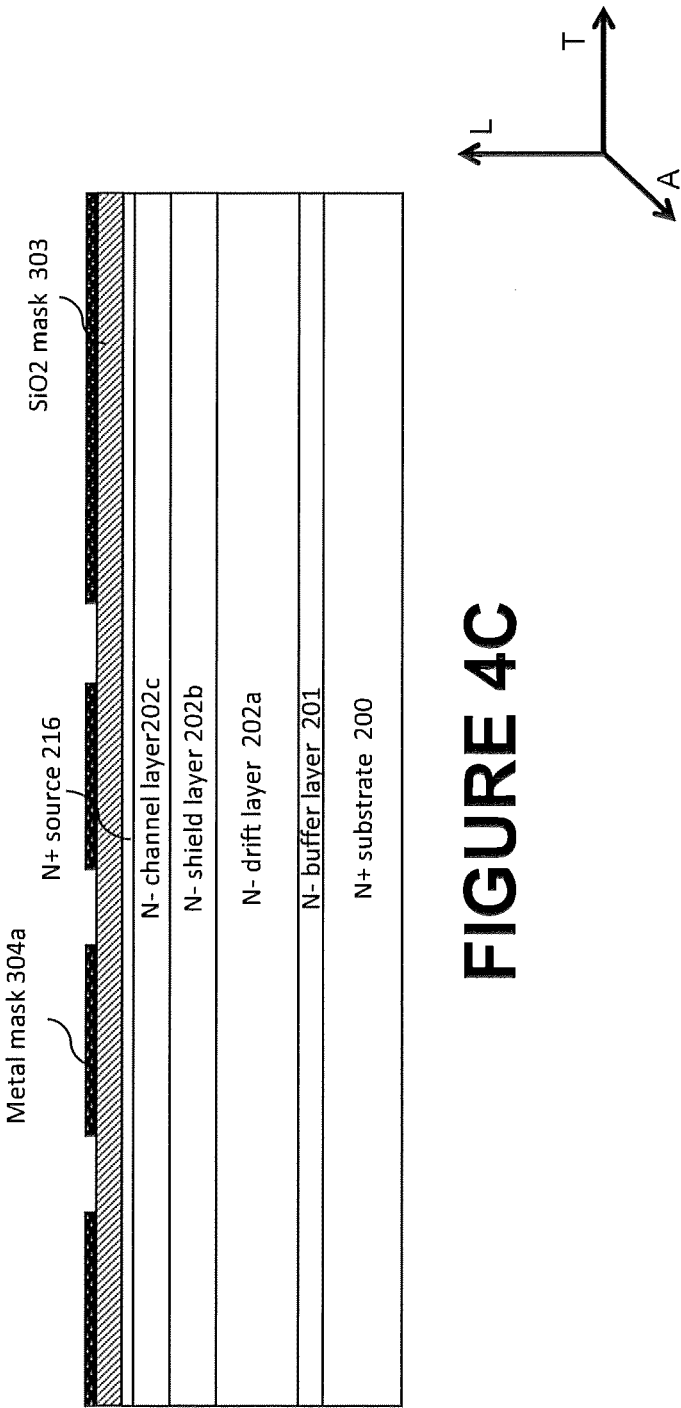


FIGURE 4C

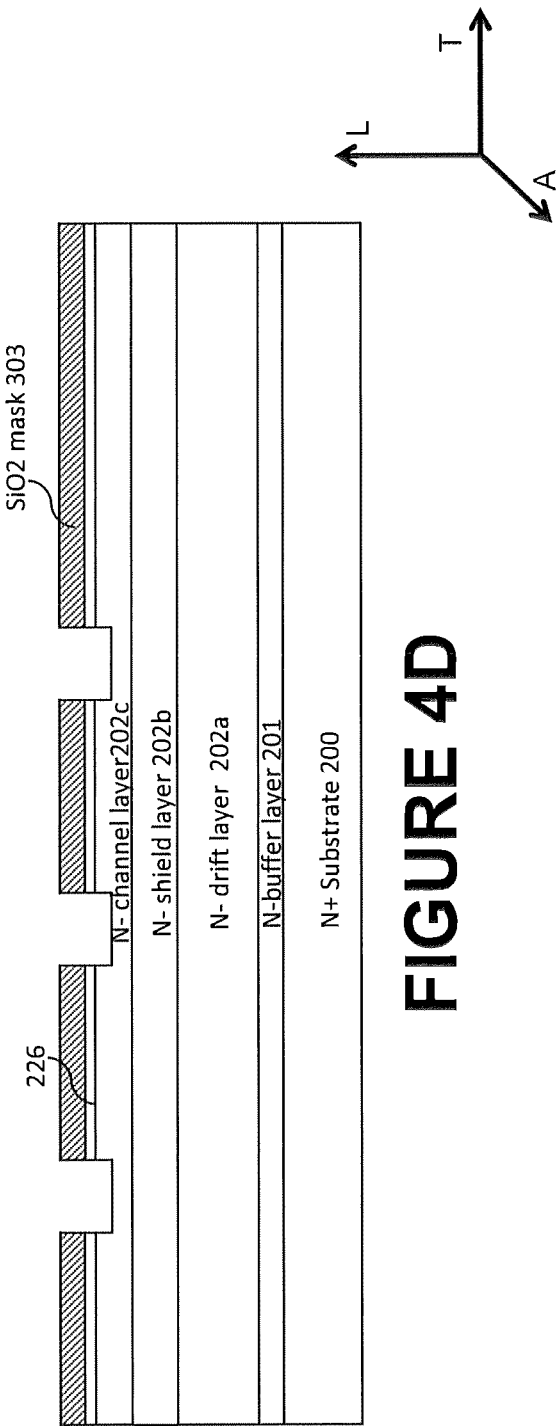


FIGURE 4D

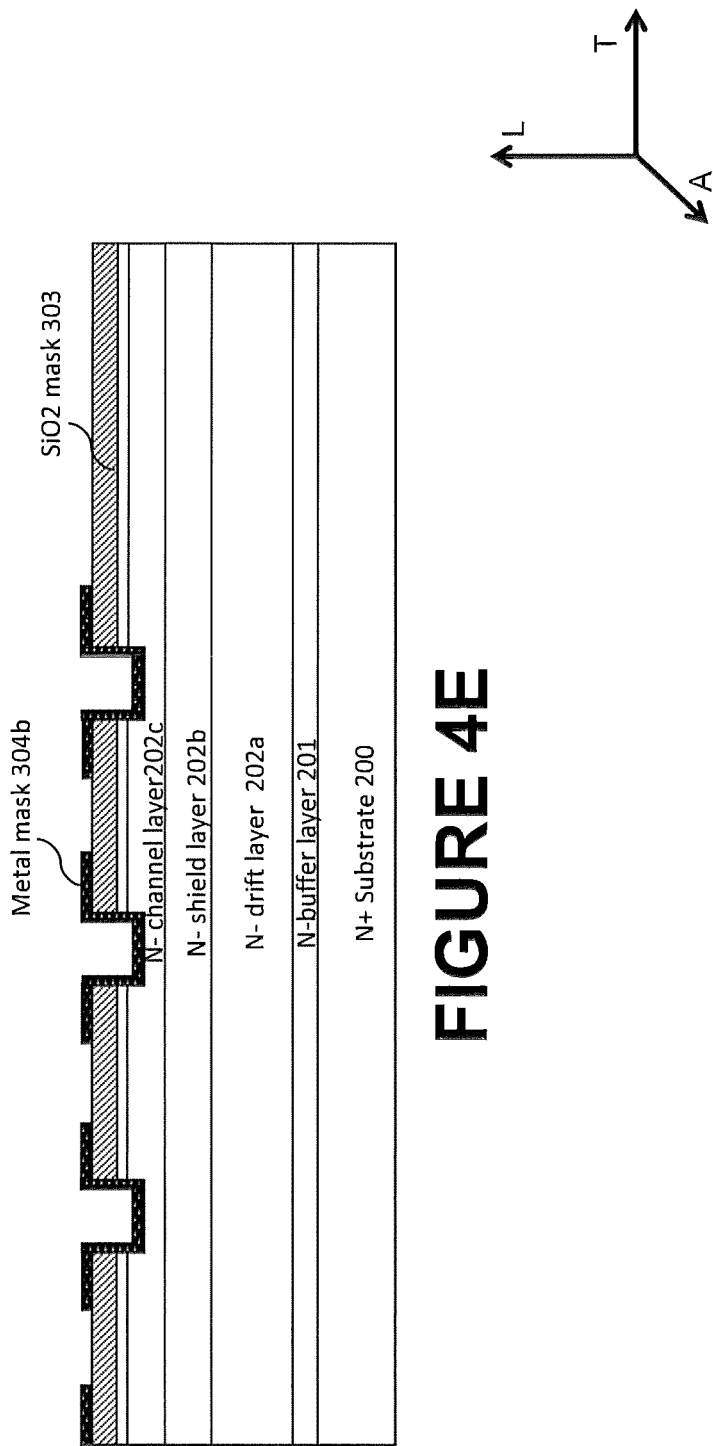
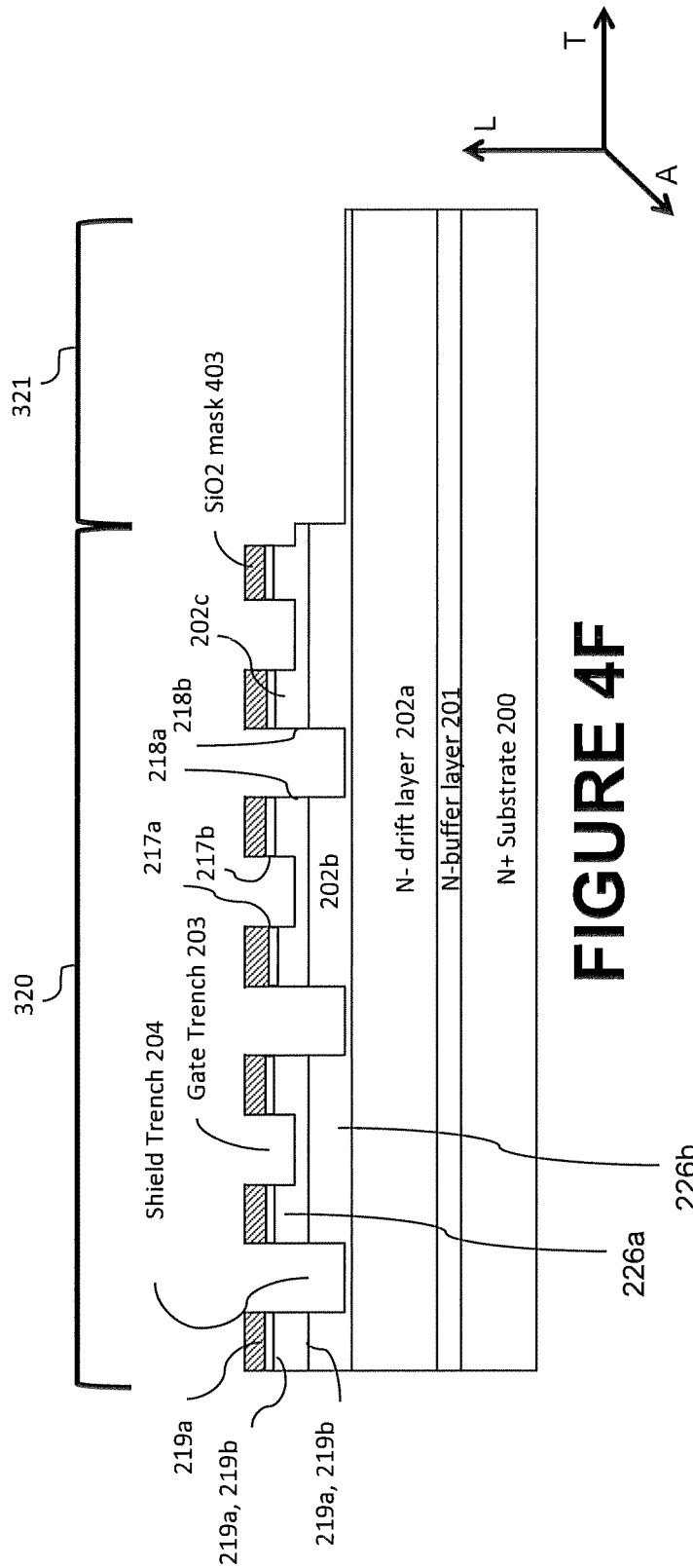


FIGURE 4E





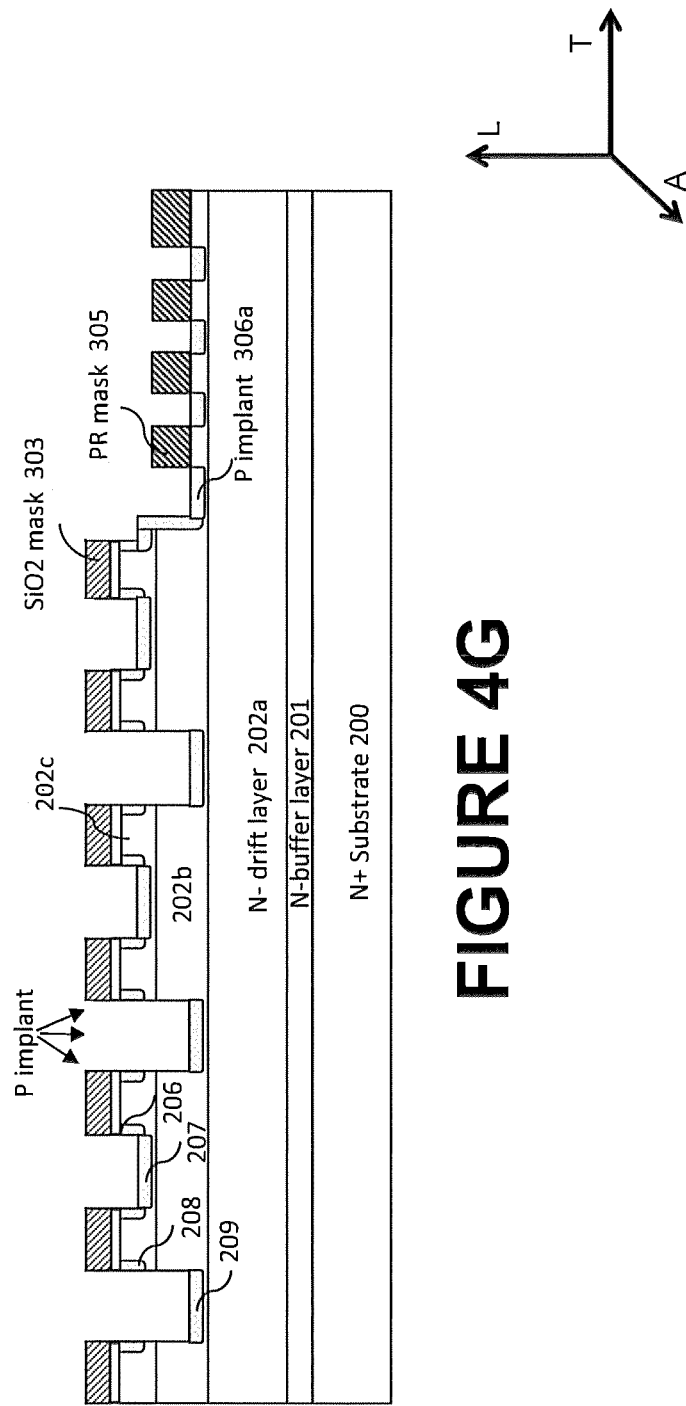


FIGURE 4G

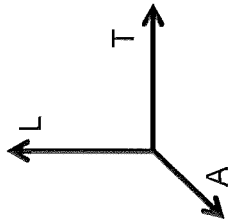
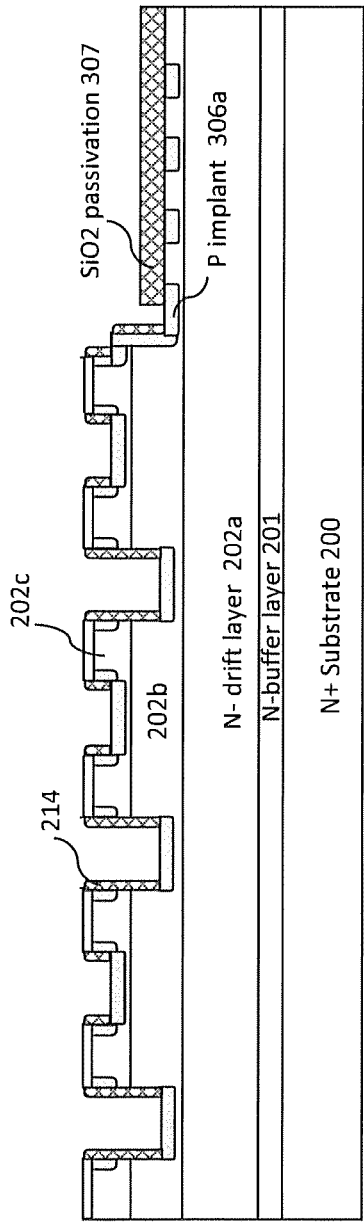


FIGURE 4H

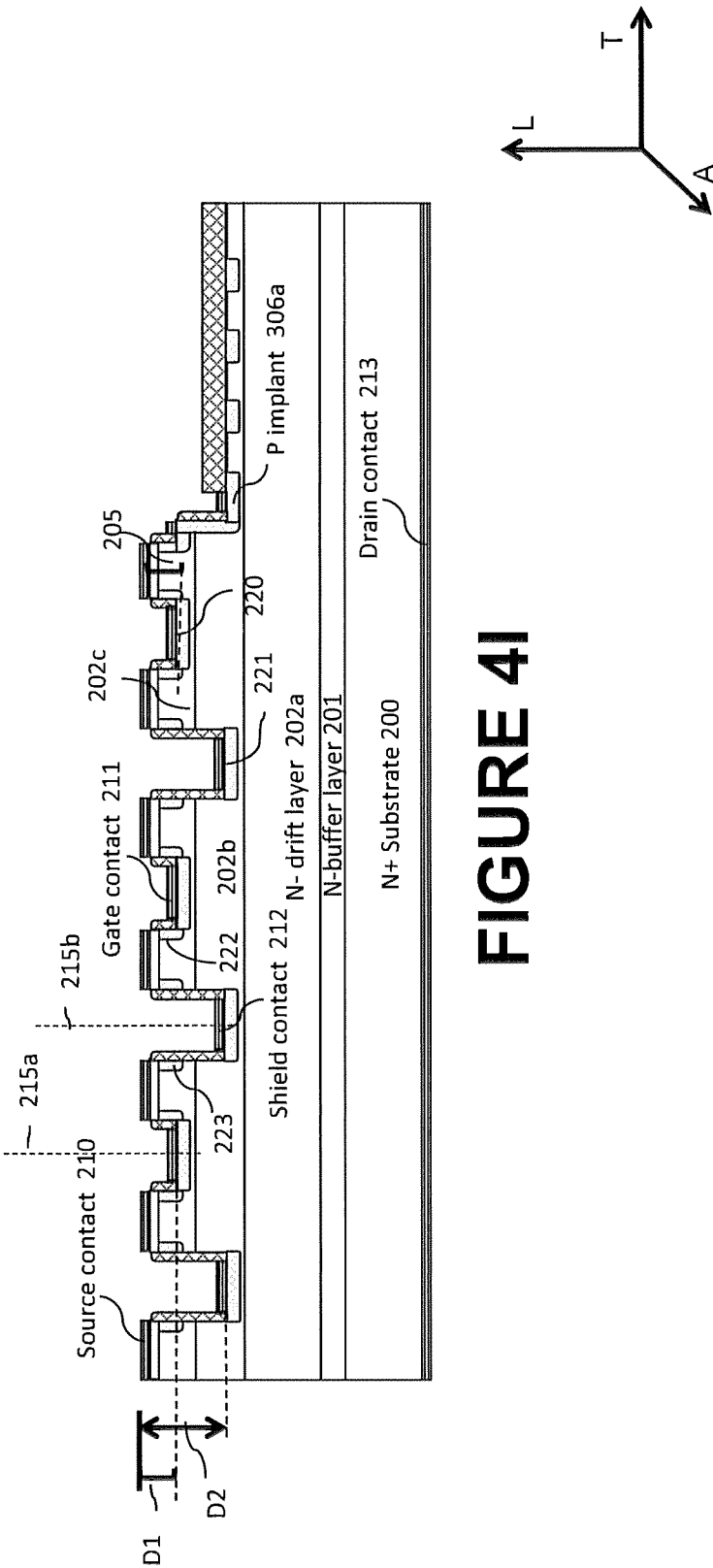
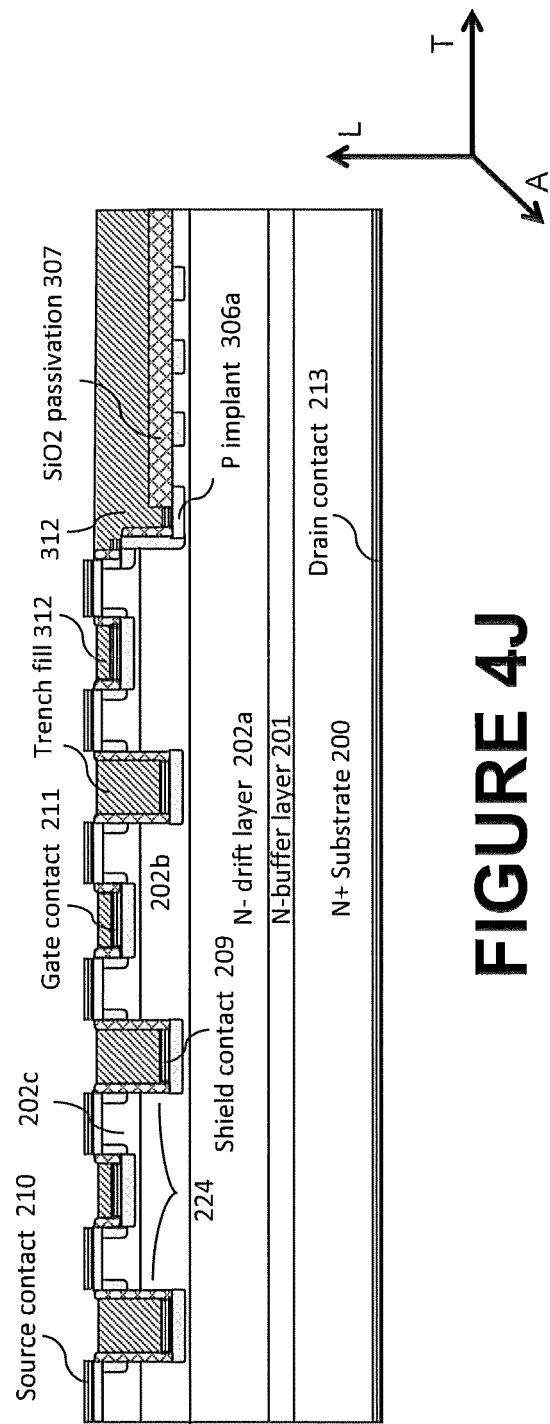


FIGURE 4I



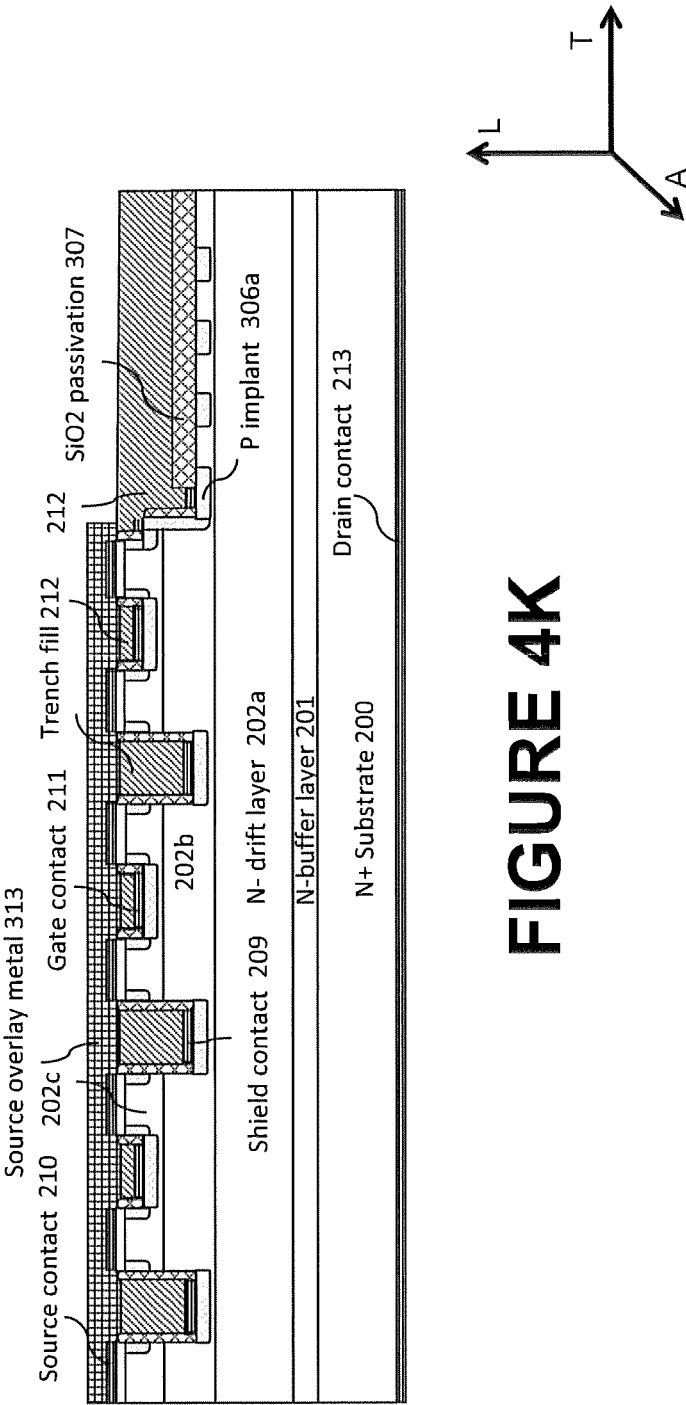


FIGURE 4K

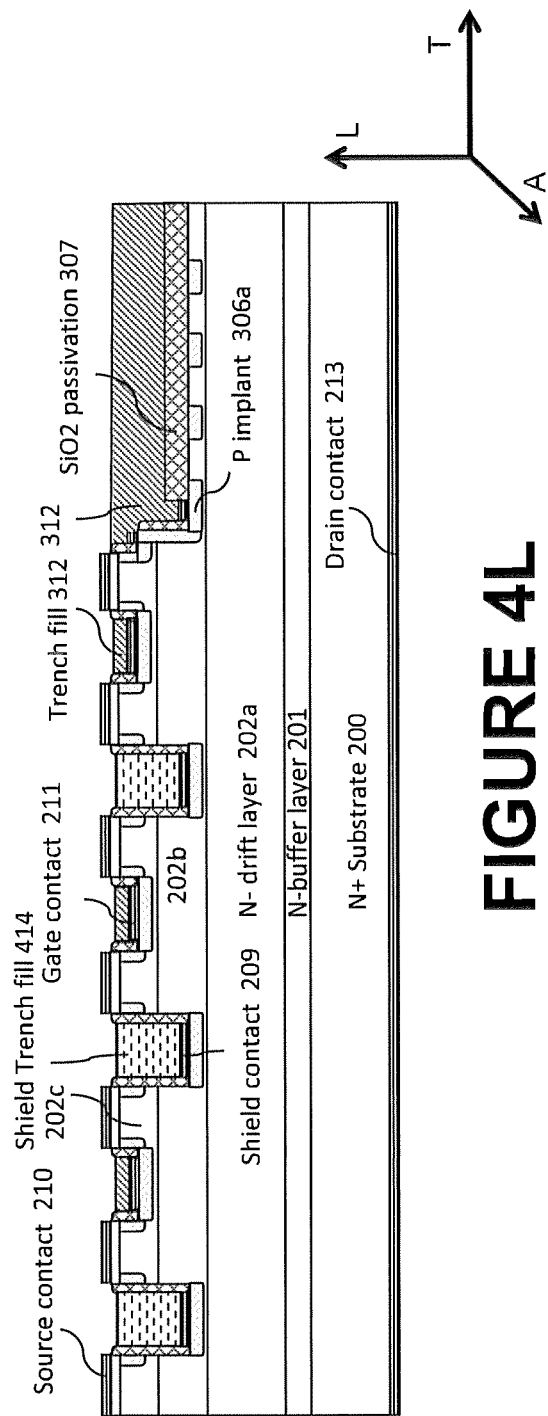


FIGURE 4L

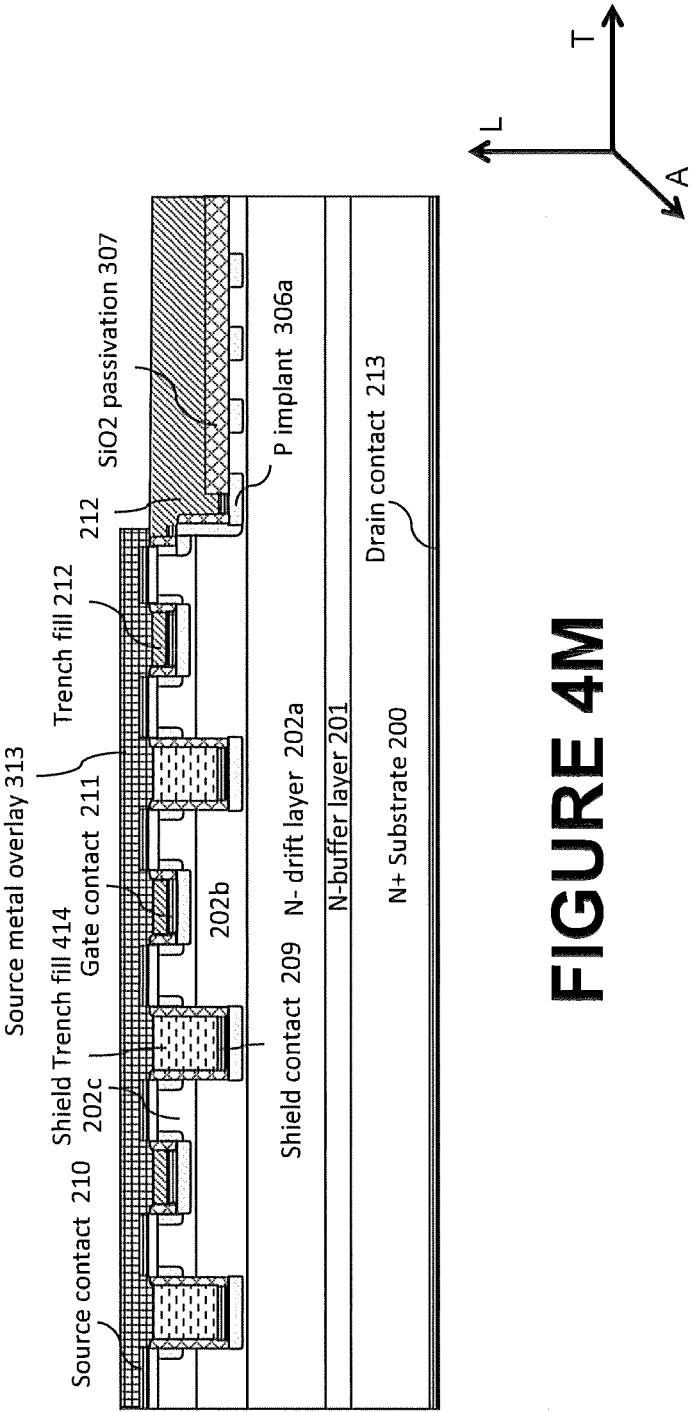


FIGURE 4M

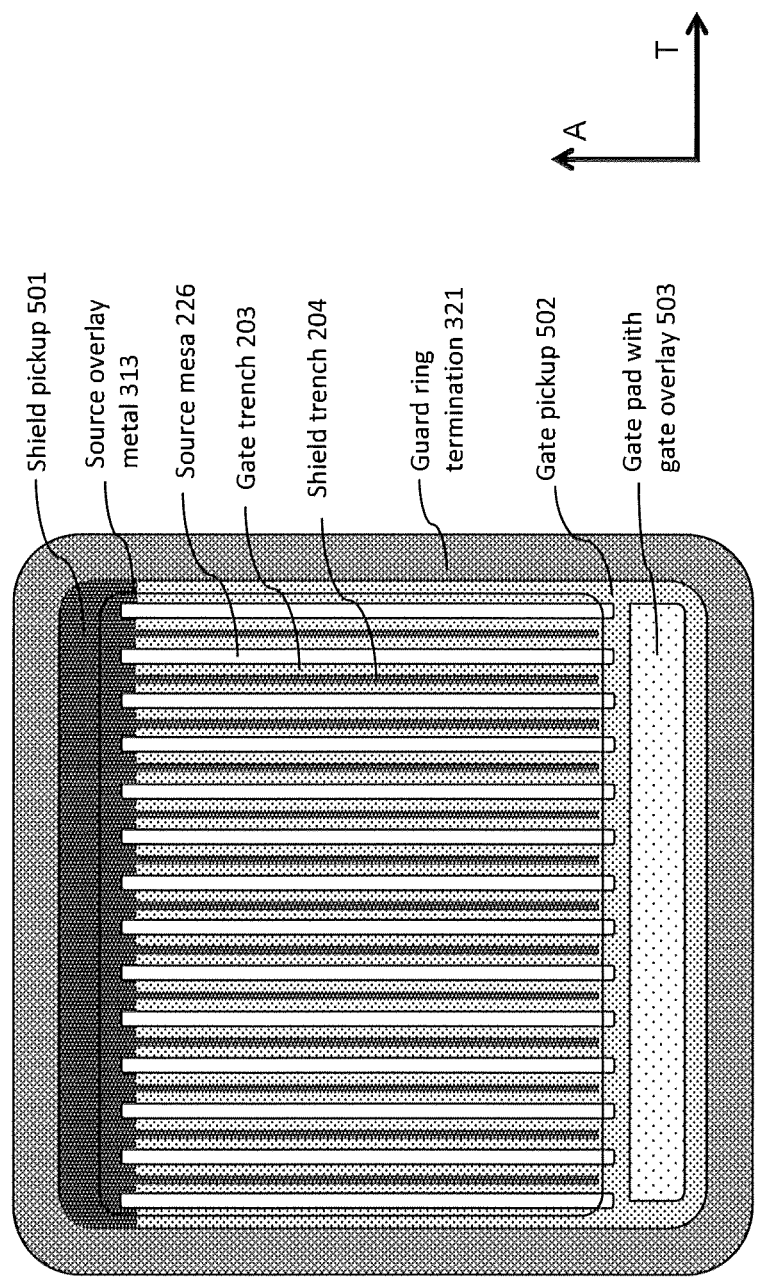


FIGURE 5A



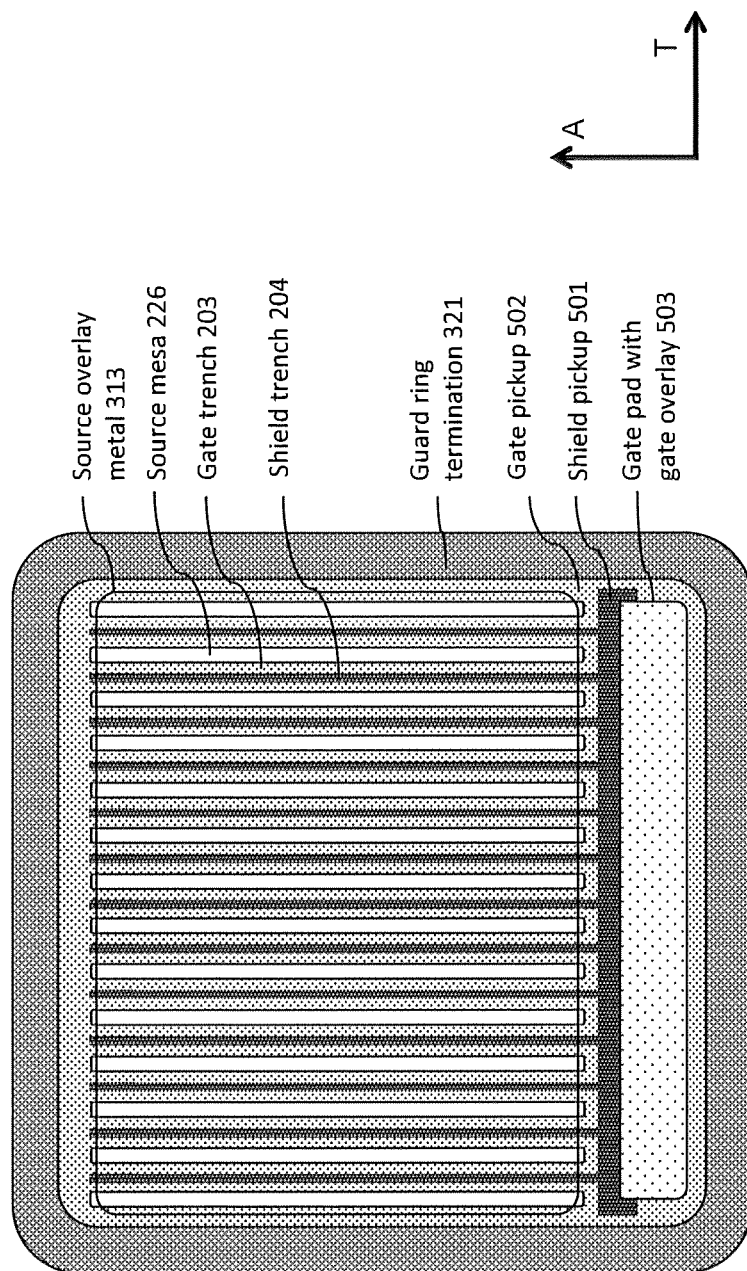


FIGURE 5B

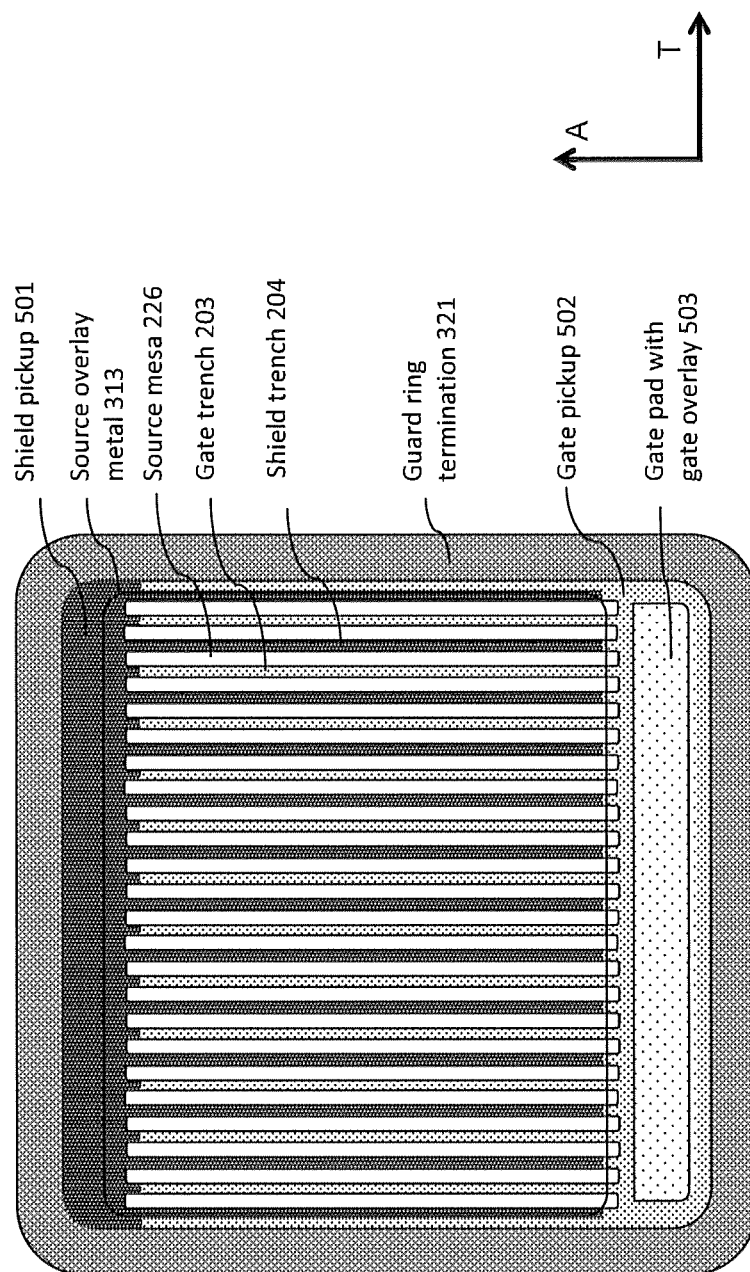


FIGURE 5C

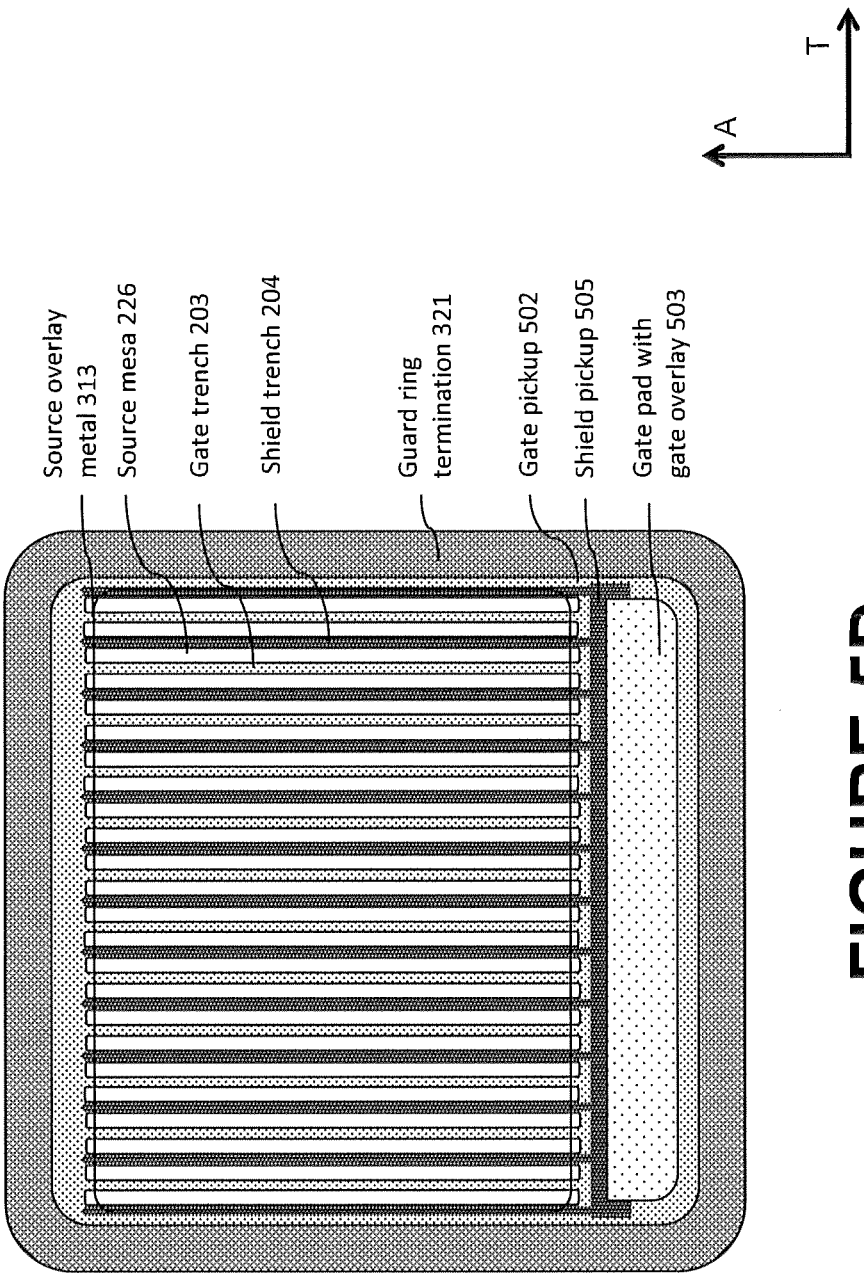


FIGURE 5D

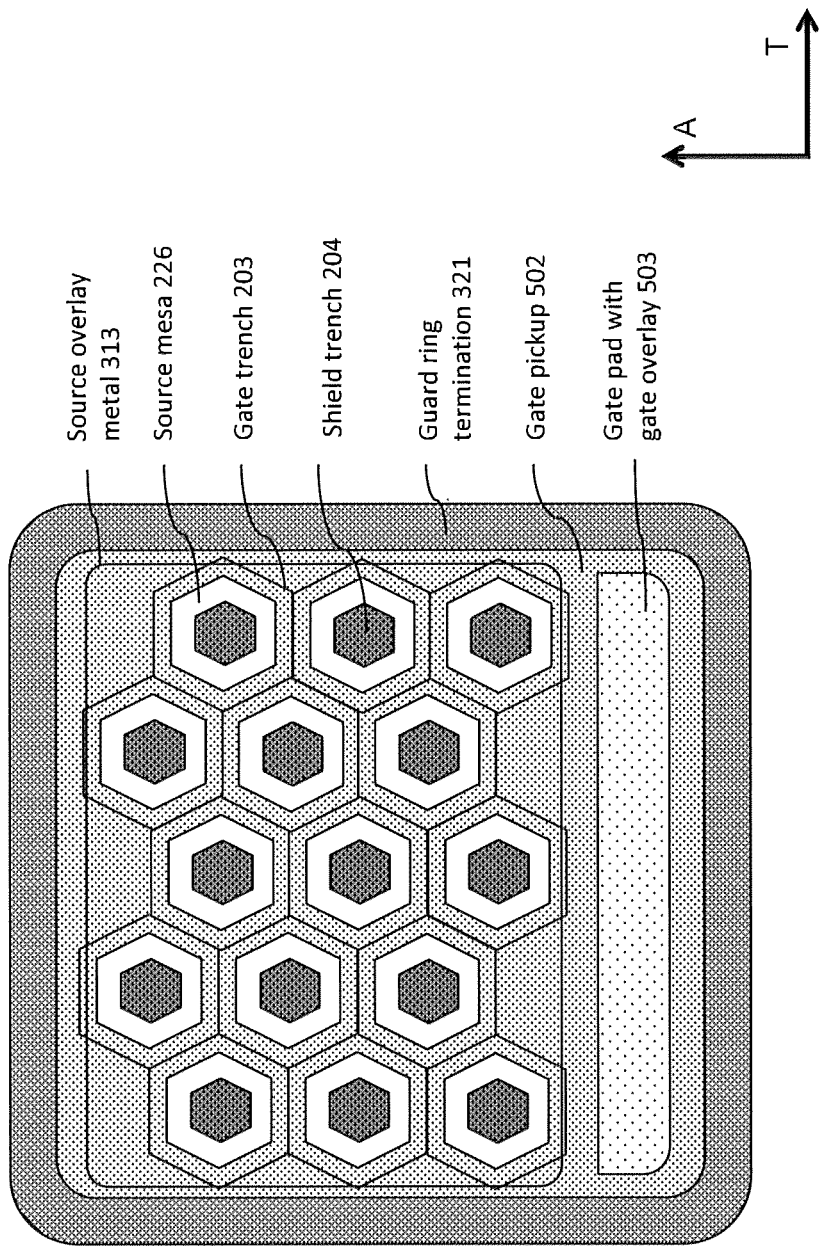


FIGURE 5E

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**TRENCH SHIELD CONNECTED JFET****CROSS REFERENCE TO RELATED APPLICATIONS**

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/831,906 filed Jun. 6, 2013 and U.S. Provisional Patent Application Ser. No. 61/833,217 filed Jun. 10, 2013 the disclosures of which are hereby incorporated by reference as if set forth in their entirety herein.

**FIELD OF THE DISCLOSURE**

The present disclosure relates to the field of high-current and high-voltage semiconductor devices, such as normally-on and normally-off vertical junction field effect transistors (VFETs) and the methods of making the same.

**BACKGROUND**

High voltage vertical junction field effect transistors (VFETs) built on Silicon Carbide (SiC) and other wide band-gap materials are of great interest for high power conversion applications due to their superior performance compared to similar devices built on Silicon (Si). Wide bandgap semiconductors have higher breakdown fields than Si that allows the use of thinner and more highly doped voltage supporting drift regions. This may directly result in many orders of magnitude reduction in device resistance in the on-state compared to a Silicon device of the same voltage rating.

VFETs are unipolar devices since they use majority carriers and usually do not suffer from the problems related to minority carrier storage. VFETs typically offer faster switching speeds and reduced switching losses. This allows for more compact power electronic circuits by reducing the size of the passive and cooling components. For unipolar devices the switching speed may be determined by the device capacitances. In hard-switched applications, such as most inductive loads like motors, low gate-drain capacitance ( $C_{GD}$ ) is critical for fast device performance.

**SUMMARY**

In accordance with the present invention, a shielded junction field effect transistors (JFET), and method of making the same, is shown and described. The shielded JFET may include a source contact, a channel area, a first trench, a gate contact, a second trench, and a shield contact.

The channel area of a first conductivity type may be disposed below the source electrode along a first direction, the channel area comprising one or more planar layers of the first conductivity type, the channel area having an upper planar surface and a lower planar surface spaced apart along the first direction.

The first trench, the first trench may have: a first bottom surface located in between the upper planar surface and the lower planar surface along the first direction, the first bottom surface extending along the first direction, a first depth that extends a first distance into the channel area from the upper planar surface of the channel layer towards the first bottom surface along the first direction, a first center line, a first pair of side walls spaced apart from one another along a second direction that is perpendicular to the first direction, the first pair of side walls extending from the first bottom surface of the first trench to the upper planar surface of the channel area; a first implanted U-shaped conductivity region of the second conductivity type in the channel area comprising: (1) a first

2

portion extending along the bottom surface of the first trench; and (2) a second portion extending from the first bottom surface of the first trench to the upper planar surface of the channel area along each of the pair of side walls. The gate contact may be disposed in the first trench and adjacent to the first bottom surface of the first trench.

The second trench, the second trench may have second bottom surface located in between the upper planar surface and the lower planar surface along the first direction, the first bottom surface extending along the first direction, a second depth that extends a second distance into the channel area from the upper planar surface of the channel layer towards the second bottom surface along the first direction, the second depth being greater than the first depth, a second center line, a second pair of side walls spaced apart from one another along the second direction, the second pair of side walls extending (1) from the second bottom surface of the first trench towards the upper planar surface of the channel area and (2) at least partially between the second bottom surface of the second trench and the upper planar surface of the channel area; a second implanted U-shaped conductivity region of the second conductivity type in the channel area comprising: (1) a first portion extending along the second bottom surface of the second U-shaped trench; (2) a second portion extending at least partially between the second bottom surface of the second trench and the upper planar surface of the channel area along each of the second pair of side walls. The shield contact may be adjacent to the second bottom surface of the second trench.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIGS. 1A-1B illustrate prior art of vertical JFET.

FIGS. 2A-2B illustrate exemplary embodiments of the trench shield VFET, where the center of the shield trench is aligned with the center of the gate trench, and the shield trench is connected to the source or the gate potential.

FIGS. 2C-2D illustrate exemplary embodiments of the trench shield VFET, where the center of the shield trench is not aligned with the center of the gate trench, and the shield trench sidewall is partially or completely implanted with the same dopant as the shield.

FIGS. 3A-3K illustrate a process for making a shielded vertical JFET, where the center of the shield trench is aligned with the center of the gate trench, and the shield trench is connected to the source or the gate potential.

FIGS. 4A-4M illustrate processes for making a shielded vertical JFET, where the center of the shield trench is not aligned with the center of the gate trench, and the shield trench is connected to the source or the gate potential.

FIGS. 5A-5E illustrate exemplary layout techniques for implementing the trench shielded vertical JFET.

**DETAILED DESCRIPTION**

The present disclosure may be understood more readily by reference to the following detailed description taken in connection with the accompanying figures and examples, which form a part of this disclosure. It is to be understood that this disclosure is not limited to the specific devices, methods, applications, conditions or parameters described and/or shown herein, and that the terminology used herein is for the purpose of describing particular embodiments by way of example only and is not intended to be limiting of the claimed embodiments. Also, as used in the specification including the appended claims, the singular forms "a," "an," and "the" include the plural, and reference to a particular numerical

value includes at least that particular value, unless the context clearly dictates otherwise. The term “plurality”, as used herein, means more than one. When a range of values is expressed, another embodiment includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another embodiment. All ranges are inclusive and combinable.

It is to be appreciated that certain features of the disclosure which are, for clarity, described herein in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the disclosure that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any sub combination. Further, reference to values stated in ranges include each and every value within that range. As shown and described herein, common reference numbers used to describe or label features of the various embodiment are intended to denote the same or similar features.

Compared to the other type of unipolar power switching device, such as the MOSFET, the VJFET may offer advantages for high power and high temperature applications. A critical characteristic of a MOSFET device is the quality of the semiconductor-oxide interface. In SiC, this interface may contain high density of carbon related surface states, which results in low electron mobility at the channel surface. VJFETs usually have a bulk channel instead of an inversion layer, so they may be fabricated with a lower on-resistance than a MOSFET of comparable voltage rating. The reliability of SiC MOSFETs at high temperatures and high electric field is a concern. An intrinsic disadvantage of SiC compared to Si for MOSFET applications is the smaller conduction band discontinuity for the SiC-oxide interface compared to Si-oxide. Moreover if the higher breakdown field of SiC is to be utilized, the oxide would be subjected to an even larger stress. This could lead to threshold voltage instability, due to carrier trapping in the gate oxide, and premature oxide breakdown, especially at high temperatures. VJFETs on the other hand are free of gate oxide and use only p-n junctions in the active device area where high electric field stress occurs and so are not subject to oxide related reliability issues. Therefore JFETs can fully exploit the high temperature capability of SiC in a voltage controlled switching device.

Devices built on SiC and other wide-band gap materials offer performance advantages, however the material is more expensive than Si. Therefore device structures that can decrease the die size are helpful to make the devices more cost-effective and allow for their widespread application.

In a conventional VJFET, the vertical channel needs to provide high potential barrier for high voltage blocking while at the same time offer low on-resistance, which are two conflicting requirements. In order to reduce the drain induced barrier lowering effect when a high drain voltage is applied, and provide high blocking voltage and reasonable on-resistance, the channel needs to be designed with a certain minimum length to width ratio for a given doping. In a trench and implanted structure making narrow and long vertical trenches is a more challenging processing task, as etching deep, narrow and closely spaced trenches with a well-controlled vertical profile is more difficult, and process non-uniformity has a greater effect on the vertical channel region width (mesa width) variation as the critical dimensions shrink. Also, doping the sidewalls of very deep trenches by ion implantation becomes a limiting factor, due to a shadowing effects from the tall mesas formed. For a given channel doping and width, a shorter vertical channel designs can

provide better on-resistance if the electric field at the lower end of the channel can be reduced.

A pure vertical channel type structure provides the lowest device on-resistance. A trench and implanted VJFET (TIVFET) of FIG. 1A is an example of a pure vertical channel type structure. However, the main disadvantage of this structure is its high gate-drain capacitance  $C_{GD}$  that limits the device speed. In order to reduce  $C_{GD}$ , different structures have been employed, such as the type of JFET shown in FIG. 1B, that utilizes a shield region 100 connected to the source. These structures reduce  $C_{GD}$ , but this comes at the expense of increased on-resistance, as they create an additional lateral channel element that adds to the device on-resistance. Further, both structures of FIGS. 1A and 1B require epi regrowth. But the long lateral channel makes for a high specific on-resistance  $R_{dsA}$ .

The VJFET structures of FIGS. 1A and 1B may be improved upon both in the on-resistance per unit area at a given voltage rating, as well as in reducing  $C_{GD}$  and enhancing switching speed. Structures may also be implemented to incorporate a built in PiN diode or JBS Schottky diode to accommodate circuits requiring bi-directional current flow. The disclosure is directed to these and other important needs.

The present disclosure provides improved design structures of a high-voltage VJFET in order to overcome the aforementioned design disadvantage. For example, an aspect of the present disclosure is to provide a VJFET with low on-resistance and low gate-drain capacitance  $C_{GD}$ . This can be accomplished with a trench shield approach that utilizes a double trench structure—a shallow trench to provide shorter vertical channel and gate channel control, and a deeper trench to provide better channel shielding from the high voltage at the drain. It is also an object of the present disclosure to provide manufacturing methods for the aforementioned structures.

The first two illustrative embodiments of FIGS. 2A and 2B utilize a double trench approach, where a deeper trench is located in, or “nested,” within a wider, shallower trench. The deeper trench—which may be referred to as the shield trench 204—functions as the shield, and the shallower trench—which may be referred to as a gate trench 203—functions as the gate. The third and fourth illustrative embodiments of FIGS. 2C and 2D use two separate trenches adjacent to each other, of two different depths, the deeper trench functioning as the shield and the shallower trench as the gate. Exemplary fabrication methods for these device structures are shown and described in the remaining figures.

FIG. 2A depicts an illustrative cross-sectional view of a shielded trench VJFET structure utilizing a double trench approach in which a second trench is “nested” within a first trench that is wider and shallower than the second trench. Thus, the second trench can be understood as overlapping the first trench. As shown in FIG. 2A, a shielded trench VJFET is built on a wafer containing a substrate 200, one or more buffer layers 201, one or more drift layers 202a, a shield layer area 202b comprising one or more shield layers, a channel layer area 202c comprising one or more channel layers, one or more source layers 216, and a source contact layer 210. Each of the substrate 200, the buffer layer(s) 201, the drift layer(s) 202a, the shield layer(s) in shield layer area 202b, the channel layer(s) in channel area 202c, the source layer(s) 216, are of a first conductivity type. Each of the substrate 200, the buffer layer(s) 201, the drift layer(s) 202a, the shield layer(s) in shield layer area 202b, the shield layer area 202b, the channel layer(s) in channel area 202c, the channel layer area 202b, and the source layer(s) 216 should be understood to be planar layers containing a first planar surface 219a and a second

planar surface **219b**, both of which extend in a first direction, such as a transverse direction T, and a second direction that is perpendicular to the first direction, such as a lateral direction A. Each first surface **219a** may be understood as being an upper surface located above the second, lower surface **219b** when moving along the longitudinal direction L—which is perpendicular to both the transverse direction T and the lateral direction A—from the substrate **200** toward the source layer **216**. Each of the substrate **200**, the buffer layer(s) **201**, the drift layer(s) **202a**, the shield layer(s) in shield layer area **202b**, the channel layer(s) in channel area **202c**, and the source layer(s) **216** also have a thickness which extends in a third direction, such as a longitudinal direction L, between the first surface **219a** and the second surface **219b**. As shown in FIG. 2A, the buffer layer(s) **201** may be located on top of the substrate **200**, the drift layer(s) **202a** may be located on top of the buffer layer(s) **201**, the shield layer(s) in shield layer area **202b** may be located on top of the drift layer(s) **202a**, channel layer(s) in channel area **202c** may be located on top of the shield layer(s) in shield layer area **202b**, the source layer(s) **216** may be located on top of the channel layer(s) in channel area **202c**, and the source contact layer **210** may be located on top of the source layer(s) **216** along the longitudinal direction L.

As further illustrated in FIG. 2A, the shielded trench VJFET also includes at least one gate trench **203** and at least one shield trench **204**. Each gate trench **203** and shield trench **204** have two side walls **217a** and **217b**, **218a** and **218b**, respectively, extending substantially in one direction, such as the longitudinal direction L, and a width extending in different direction, such as the transverse direction T, between the two side walls. As depicted in FIG. 2A, the gate trench **203** has a width that is greater than the width of the shield trench **204**.

Each gate trench **203** and shield trench **204** also have a depth extending in another direction, such as the longitudinal direction L, that is perpendicular to the width. The depth of gate trench **203** D1 may be defined as the distance between the upper surface **219a** of the source layer **216** and a bottom surface **220** of the gate trench **203**. The depth of the shield trench **204** D2 may be defined as the distance between the upper surface **219a** of the source layer **216** and a bottom surface **221** of the shield trench **204**. The bottom surfaces **220**, **221** of each of the gate trench **203** and the shield trench **204** extends in the transverse direction T. The bottom surfaces **220**, **221** of the gate trench **203** and the source trench **204** are located between the upper surface **219a** and the lower surface **219b** of the channel layer area **202c** and the shield layer area **202b**, respectively. As depicted in FIG. 2A, each gate trench **203** has the same depth D1 and each shield trench **204** has the same depth D2. Further, the depth D2 of each shield trench **204** is greater than the depth D1 of gate trench **203** along the longitudinal direction L. It should be understood that each of gate trench **203** may extend at least partially through the channel layer area **202c**, and each of shield trench **204** may extend at least partially through the shield layer area **202b** along the longitudinal direction L.

The width of each gate trench **203** may be understood as being centered about a centerline **215a**, where centerline **215a** extends in the longitudinal direction L. Similarly, the width of each shield trench **204** may be understood as being centered about a centerline **215b**, where centerline **215b** extends in the longitudinal direction L. Using centerlines **215a** and **215b** as a reference, shield trench **204** may be understood as being located within (e.g., nested in) the gate trench **203** in a variety of ways. For example, centerlines **215a** and **215b** may be aligned with one another along the trans-

verse direction T, as shown in FIGS. 2A and 2B, such that the shield trench **204** is centered in the gate trench **203**. Alternatively, centerlines **215a** and **215b** may be offset (e.g., not aligned) a distance along the transverse direction T such that shield trench **204** is located, but not centered, in gate trench **203**. For example, the centerlines **215a** and **215b** may be offset along the transverse direction T such that (1) side wall **217a** of the gate trench **203** is aligned with one of the side walls **218a** and **218b** of the shield trench **204** or (2) side wall **217b** of the gate trench **203** is aligned with one of the side walls **218a** and **218b** of the shield trench **204**.

As depicted in FIG. 2A, side walls **217a**, **217b** of the gate trench **203** extend from the bottom surface **220** of the gate trench **203** to the upper surface **219a** of the source layer **216**. Further, side walls **218a**, **218b** of the shield trench **204** extend (1) from the bottom surface **221** toward upper surface **219a** of the source layer **216** and (2) at least part of the distance between the bottom surface **221** and upper surface **219a** of the source layer **216** (e.g., depth D2). For example, one or both of side walls **218a**, **218b** may extend between the first bottom surface **220** of the gate trench **203** and the second bottom surface **221** of the shield trench **204**. Alternatively, one or both of side walls **218a**, **218b** may extend between the second bottom surface **221** of the shield trench **204** and upper surface **219a** of the source layer **216**. The example shown in FIG. 2A, as an example, shows both of side walls **218a**, **218b** extending between the first bottom surface **220** of the gate trench **203** and the second bottom surface **221** of the shield trench **204**.

Implanted regions of a second conductivity type may be located in sidewalls and bottom each of the gate trench **203** and the shield trench **204**. The bottom **220** of the gate trench **203** may contain an implanted region **207** connected to implanted regions **206** in each of sidewall **217a**, **217b** of the gate trench **203** to collectively form a U-shaped conductivity region **222** of the second conductivity type in the gate trench **203**. Further, implanted regions **206** may extend along sidewalls **217a**, **217b** through the channel layer(s) in channel area **202c** only—the N<sup>+</sup> layer **216** having a doping concentration of the first conductivity type sufficiently large to prevent the creation regions of the second conductivity type by implantation. For figure clarity, the first conductivity type is shown as n type, and the second conductivity type is shown as p type, however the opposite configuration with the first conductivity type being p type, and the second conductivity type being n type is also possible. The bottom **220** of the gate trench and the bottom **221** of the shield trench may be implanted to higher doping concentration at the surface to alleviate formation of ohmic contacts.

Continuing with FIG. 2A, sidewalls **218a**, **218b** and the bottom of the shield trench **204** may contain implanted regions of the second conductivity. For example, the bottom **221** of the shield trench **204** may contain an implanted region **209** and each sidewall **218a**, **218b** may contain implanted regions **208** to collectively form a U-shaped conductivity region **223** of the second conductivity type in the shield trench **204**. Implanted regions **208** may extend partially along sidewalls **218a**, **218b** in the epi layers **202**. For example, as depicted in FIG. 2A, the implanted regions **208** extend from the bottom surface **220** of the gate trench **203** toward the bottom **221** of the shield trench **204** along only part of sidewalls **218a**, **218b**. An unimplanted region **224** of the first conductivity type extends along the remainder of sidewalls **217a**, **217b**, the unimplanted region **224** being disposed between the bottom surface **221** of the shield trench **204** and implanted regions **208** along the longitudinal direction L.

Staying with FIG. 2A, metal regions at the top of the VJFET structure provide a source contact **210** and metal

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regions located adjacent to the bottom of each of the respective shield trenches provide a shield contact **212**. The shield contact **212** at the bottom of the shield trench **204** are, in this example, connected to the source contact **210** at a shield pickup location disposed elsewhere in the device so as to hold the shield contact **212** at source potential. For example, the shield pickup location may be disposed proximate to an edge of the device—as is discussed elsewhere in this disclosure. By connecting one or more of the shield region **208** to the source, the gate-drain capacitance may be reduced, compared to a conventional VJFET structure. Metal regions located adjacent to the bottom of each of the respective gate trenches **203** provide at least one gate contact **211** per gate trench **203**. Metal regions at the wafer back side provide a drain contact **213**. Dielectric spacers **214** on the sidewalls **217**, **218** of the trenches **203** and **204** provide gate-to-source and gate-to-shield isolation.

According to various embodiments disclosed herein, individual vertical channel regions **205** may be defined as a region of the channel layer area located in-between a first gate trench **203** and a second trench—which may be a gate trench **203** or a shield trench **204**—adjacent to the first gate trench **203** and implanted regions **206**, **207**, and **208** in the side walls **217a**, **217b**, **218a**, **218b** of the adjacent trench along the transverse direction T. The second, adjacent trench may be located on either side of the first trench along the transverse direction T. For example, in the embodiment depicted in FIG. 2A, an example of a vertical channel region **205** may be defined as the region of channel layer area **202c** between the implanted region **206** in the sidewall **217b** of a first gate trench **203** and the implanted region **206** in the sidewall **217a** of a second, adjacent gate trench **203** along the transverse direction T.

In various embodiments, two trenches disposed a distance apart from one another along, for example, the transverse direction T, may form a mesa comprised of one or both of the channel layer area **202c** and the shield layer area **202b** and defined by the distance. For example, in FIG. 2A, a first nested gate trench **203** and shield trench **204** pair are spaced a distance apart from a second nested gate trench **203** and shield trench **204** pair along the transverse direction T. The portion of one or more of shield layer(s) in shield layer area **202b**, channel layer(s) in channel area **202c**, and source layer(s) **216**, located between the first and second pairs along the transverse direction T may be understood as forming a mesa **226**. In an embodiment, where one or both of the first and the second nested pairs contain a gate trench **203** fully aligned with a shield trench **204**, mesa **226** may contain one or two steps **228**. A step **228** refers to a portion of the bottom surface **220** of the gate trench **203** located adjacent to the shield trench **204** along the transverse direction.

In the embodiment, such as the one depicted in FIG. 2A, where the sidewalls are partially implanted, the implanted region **209** in the bottom of the shield trench **204** may be utilized in order to provide an electrostatic shield to reduce the electric field at the vertical channel region **205**. This allows for the use of a shorter vertical channel region **205** in order to reduce the device on-resistance. Further, the spacing between the p-regions **208** and **209** may be designed to ensure that the punch-through voltage between the gate and source/shield has a greater magnitude than the vertical channel region **205** pinch-off voltage. This may be done by ensuring a sufficient gap between p-regions **208** and **209**.

FIG. 2B illustrates a cross-sectional view of another example of a trench shield VJFET with aligned gate and shield trenches and shield connected to the gate. In the device of FIG. 2B, shield contacts **212** located adjacent to the bottom of each respective shield trench **204** are, in this example,

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connected to the gate contact **211** at a shield pickup location disposed elsewhere in the device so as to hold the shield contact **212** at gate potential. For example, the shield pickup location may be disposed proximate to an edge of the device—as is discussed elsewhere in this disclosure. Alternatively, implanted regions **208** may extend the entire length of sidewalls **218a**, **218b** located in the shield epi layer (2) in shield layer area **202b**. The connection to the shield contacts **212** may also be provided through the implanted regions **208** when they extend the entire length of sidewalls **218a** and **218b**. This embodiment may provide identical improvement in on-resistance as the embodiment of FIG. 2A. But, by connecting the shield region to the gate, the gate-drain capacitance may no longer be reduced, compared to a conventional VJFET structure. However, the fabrication complexity of the embodiment of FIG. 2A may be alleviated by the embodiment of FIG. 2B—which eliminates concerns associated with the device of FIG. 2A for gate-source shorting through the shield trench **204** implanted sidewall regions **208** and the metal regions **211** and **212**.

FIG. 2C illustrates an exemplary cross-sectional view of another embodiment of a trench shield VJFET in which respective gate trenches **203** and shield trenches **204** are separated such that they do not overlap. The gate trenches **203** and shield trenches **204** of FIG. 2C can therefore be understood as being offset. In particular, FIG. 2C illustrates an example in which centerlines **215a** of gate trenches **203** and centerline **215b** of shield trench **204** are offset (e.g., not aligned) a distance along the transverse direction T such that shield trench **204** is completely separate from gate trench **203**. In other words, the gate trench **203** and the shield trench **204** are offset a distance sufficient to prevent any overlap between the gate trench **203** and the shield trench **204**. Further, although FIG. 2C depicts shield trenches **204** and gate trenches **203** positioned in an alternating pattern along the transverse direction T, it should be understood that gate trenches **203** and shield trenches **204** can be arranged in any order. There may also be an unequal number of gate trenches **203** and shield trenches **204**. As described above, in respective gate trenches **203**, regions **206** are connected to the gate potential, while individual regions **208** may be connected to either the gate or the source potential. The bottom **220** of the gate trench **203** is implanted to form a region **207** with a conductivity of a second type that is connected to the sidewall implanted regions **206**. The sidewalls **218a**, **218b** of the shield trench **204** may be partially implanted to form regions **208** with a conductivity of second type, and the bottom **221** of the shield trench **204** is implanted to form a region **209** with a conductivity of second type that provides an electrostatic shield to reduce the electric field at the vertical channel regions **205** so that a shorter vertical channel regions **205**, along the longitudinal direction L, can be used in order to reduce the device on-resistance. In an example embodiment, the contact **212** at the bottom of the shield trench is connected to the source potential at a shield pickup location. In this embodiment, if the sidewall p-regions **208** are connected to gate potential, sufficient spacing may be designed between regions **208** and **209** to ensure that the punch through voltage between them exceeds the channel **205** pinch-off voltage by a sufficient margin. If instead, the region **208** is connected to source potential, then the vertical channel region **205** doping may be designed to ensure that the punch-through voltage between regions **208** and **206** exceeds the vertical channel region **205** pinch-off voltage by a sufficient margin. It should be understood that a configuration of the same structure is possible, where the shield is connected to the gate potential.



In the example depicted in FIG. 2C, vertical channels **205** may be defined as the region of channel layer area **202c** between the implanted regions **206** in the sidewalls **217a**, **217b** of a first gate trench **203** and the implanted regions **208** in the sidewalls **218b**, **218a**, respectively, of adjacent shield trenches **204**.

The embodiment depicted in FIG. 2C contains two types of mesas: channel mesas **226a** and combined channel-shield mesas **226b**. For example, one or more channel mesas **226a** may be defined by an adjacent gate trench **203**—shield trench **204** pair, the pair being spaced a distance apart along the transverse direction T. The portion of one or more channel layer(s) in channel area **202c** and source layer(s) **216**, located between gate trench **203**—shield trench **204** pair may be understood as forming individual mesas **226a**. Further, one or more combined channel-shield mesas **226b** may be defined a pair of adjacent shield trenches **204** spaced a distance apart along the transverse direction T. The portion of one or more shield layer (a) in shield layer area **202b**, channel layer(s) in channel area **202c** and source layer(s) **216**, located between the pair of shield trenches **204** may be understood as forming individual mesas **226b**. Individual mesas **226b** may also be understood as including two channel mesas **226a** and a gate trench **203**.

FIG. 2D illustrates an exemplary cross-sectional view of a trench shield VJFET with separated gate trenches **203** and shield trenches **204** as well as a shield connected to the source potential. Region **206** in FIG. 2D is connected to the gate potential, while region **208** is connected to the shield (source) potential. Further, region **209** in the bottom **221** of the shield trench **204** is connected to the sidewall implanted regions **208**—which extend the entire length of sidewalls **218a**, **218b** located in the channel epi layer area **202c** and shield epi layer area **202b**. The sidewalls of the shield trench are fully implanted to form regions **208** with a conductivity of second type, and the bottom of the shield trench is implanted to form a region **209** with a conductivity of second type that provides an electrostatic shield to reduce the electric field at the channel so that a shorter vertical channel region **205** can be used in order to reduce the device on-resistance. The metal contact disposed adjacent to the bottom of the shield trench is connected to the source potential at a shield pickup location elsewhere on the device. Further, channel **205** doping may be designed to ensure that the punch-through voltage between regions **208** and **206** exceeds the vertical channel region **205** pinch-off voltage by a sufficient margin. In this embodiment, it may be also possible to achieve local shorting between the shield and source by etching down the sidewall spacers **214** selectively in the shield trench **204**, exposing part of the sidewall implanted region **208** to be shorted to the source **210** when the source electrode is formed. It should be understood that a configuration of the same structure is possible, where the shield is connected to the gate potential.

It should be understood that a device may comprise a combination of those trenches depicted in each of FIGS. 2A, 2B, 2C, and 2D.

FIGS. 3A-3K illustrate an exemplary process for the fabrication of the shielded vertical JFETs such as those devices shown and described in connection with FIGS. 2A and 2B.

FIG. 3A illustrates an exemplary starting wafer. The process begins as illustrated in FIG. 3A with the growth of one or more the epitaxial (epi) buffer layers **201**, followed by one or more drift epi layers **202a**, one or more shield layers in shield layer area **202b**, one or more channel layers, and then one or more source layers **216**, on the substrate **200**. It should be understood that the substrate **200** may also be referred to as the substrate layer. It should be understood that the epitaxial

buffer layer **201** may also be referred to as the buffer layer. Alternatively, the shield layer(s) in shield layer area **202b** and the channel layer area **202c** may be formed by implantation into the drift layer **202a**, in which case the doping where these layers will be formed is kept light during epitaxial growth, allowing the actual doping to be precisely set by implantation after growth.

FIGS. 3B-3D illustrate an exemplary process for the formation of a composite oxide or SiO<sub>2</sub> mask **303** and metal mask **304a** (hardmask) by deposition and lithography, followed by the oxide and shallow trench etch. FIG. 3B illustrates the formation of the implant SiO<sub>2</sub> mask **303**. FIG. 3C illustrates the formation of the first etch metal mask **304a**. FIG. 3D illustrates the first trench etch which results in gate trench **203**.

FIG. 3E illustrates an exemplary process for the utilizing a second etch mask layer **304b**. FIG. 3E shows the deposition and patterning of the second etch mask layer **304b** with an opening within the shallower trench bottom plane. It should be understood that second etch mask layer **304b** may also be referred to as second metal mask layer. As compared to the first etch mask **304a**, the opening of the second etch mask layer **304b** is smaller. Second etch mask layer **304b** may be formed by, for example, by removing first etch mask **304a** prior to forming second etch mask **304b** or by depositing additional material to the first etch mask **304a** to form second etch mask **304b**.

FIG. 3F illustrates an exemplary process for doing a second trench etch. FIG. 3F shows the appearance of the wafer after the formation of the deeper shield trench **204** by etching—using the second metal mask **304b** with its narrow openings as the hardmask. FIG. 3F is shown with the metal removed by, for example, selective wet etching.

As illustrated in FIG. 3F, an array of mesas **226** with at least one step **228** may be formed for the active area **320**, while termination area **321** and shield pickup area **501** (FIG. 5A) is etched down to the level of the shield trench **204** where the termination and shield pickup regions will be formed. In a gate pickup area **502** (FIG. 5A) the deeper shield trench **204** etch is not done where the gate pickup regions will be by ensuring that the gate pickup area **502** remains covered by the second metal mask **304b** during the trench etch. It should be understood that the termination area **321** may be referred to as guard ring termination area.

FIG. 3G illustrates an exemplary process for the formation of a gate implant. FIG. 3G shows the application of a guard ring mask, where the photoresist mask **305** defines guard ring spaces, while being fully cleared in the active area **320**. It may be understood that photoresist mask **305** may also be referred to as PR mask. Vertical and tilted p-implants are then performed at room temperature to form the implanted regions around the gate trench **203**, and the shield trench **204** such as implanted regions **206**, **207**, **208**, **209** in the side walls **217a**, **217b**, **218a**, **218b** of the gate trench(es) **203** and shield trench (es) **204** and also P implant **306a** regions (also known as guard ring implants). It will be appreciated that implanted regions **206**, and **208** may be formed before, during, or after implanted regions **207** and **209**—which accounts for the variation between depicted configuration of implanted regions **206**, **207**, **208**, **209** in FIG. 3G vs. FIGS. 2A and 2B. The vertical and tilted p-implants may have different doses and may create different doping concentration on the bottom of the trenches **203** and **204**, in regions **207** and **209**, and on the trenches side walls **217a**, **217b**, **218a**, **218b**, in regions **206** and **208**. The implanted concentration regions **207** and **209**, close to the surface of the trenches **203** and **204**, may be higher in order to alleviate formation of ohmic contacts. The

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implant angle control based on the cell geometry may assure that there are no short forms along the deep trench sidewall. Should a high temperature implant be needed, the photoresist mask **305** may need to be replaced by materials such as refractory metal, polysilicon, oxide, or nitride, or the like. In the example, once the resist is stripped, the oxide is stripped, the wafer may be cleaned and subjected to implant anneal. Techniques such as surface graphitization may be applied, and the annealing ambient and temperature chosen to achieve dopant activation. The wafers may then be cleaned to remove the graphite cap, and a thin oxide may then be grown to consume the damaged surface and improve surface behavior. It may be understood that guard ring termination type shown may be substituted with a different type of termination, such as junction termination extension (JTE). In such a case the implants needed to form the JTE may need to be done in a separate implant step during which the active area may or may not be implanted.

FIG. 3H illustrates an exemplary passivation and exemplary formation of ohmic contact windows. As depicted in FIG. 3H, dielectric spacers **214** are deposited, and etched back with a mask (not shown) protecting the termination regions to form spacers in the active region **320** and a SiO<sub>2</sub> passivation layer **307** in the termination area **321**. The mask may be referred to as the ohmic contact window mask.

FIG. 3I illustrates an exemplary formation of ohmic contacts. FIG. 3I illustrates how a contact metal such as Nickel may be deposited, and silicided with techniques such as rapid thermal or furnace annealing, followed by wet etching of the excess unreacted Nickel to form the ohmic contacts to the gate **211**, source **210**, shield **212** and shield pickup contact regions **501** (FIG. 5A). In this example, in order to form the drain contact **213** with the same anneal, the backside films are first stripped with the frontside protected by a photoresist, a layer of material such as Nickel is deposited on the back, the protective resist is removed, and then both the top and bottom surfaces are subjected to a single anneal.

FIG. 3J illustrates an exemplary trench fill. FIG. 3J shows how the trenches are filled by a dielectric **312** (also known as trench fill passivation), such as silicon dioxide (SiO<sub>2</sub>). Techniques such as BPSG fill and reflow, multiple oxide deposition and etch back sequences, or the like may be used to achieve this.

FIG. 3K illustrates an exemplary metal overlay and final passivation. FIG. 3K shows how an overlay metal **313** (also known as a source metal overlay) may be patterned on the device to form the gate and source metal pads. The device is now complete, and an optional step may be performed to further passivate the device surface with a patterned low temperature oxide, nitride, polyimide or BCB and define bond pad openings therein.

FIGS. 4A-4M illustrate exemplary processes for the fabrication of the exemplary device of illustrated in FIG. 2C, that can be easily adapted to exemplary device illustrated in FIG. 2D.

FIG. 4A illustrates a starting wafer. As illustrated in FIG. 4A, the process begins with the growth of the epitaxial buffer layer **201**, followed by the drift layer **202a**, and then the shield layer area **202b**, the channel layer area **202c** and the n+ source layers **216** on the substrate **200**. If it is preferred to form some or all of the layers in areas **202b**, **202c**, and **216** by implantation, then the doping for these layers is kept light during epitaxial growth, allowing the actual doping to be precisely set by implantation.

FIGS. 4B-4D illustrate an exemplary process for the formation of the composite oxide or SiO<sub>2</sub> mask **303** and metal mask **304a** (hardmask) by deposition and lithography, fol-

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lowed by the oxide and shallow trench etch. FIG. 4B illustrates an exemplary oxide deposition (i.e. implant anneal in case of implanted n+). FIG. 4C illustrates an exemplary first etch mask. FIG. 4D illustrates first trench etch and a mesa **226** as described in FIG. 2A.

FIG. 4E illustrates an exemplary the second metal deposition, such as metal mask **304b** and patterning. FIG. 4F illustrates an exemplary second etch mask **304b**.

FIG. 4F shows an exemplary oxide and deeper trench etch using this second etch metal mask **304b** (hardmask), followed by metal stripping using techniques such as wet etching that do not affect the oxide of material such as Silicon Carbide. FIG. 4F illustrates an exemplary second trench etch. Note the formation of alternating shallow and deep trenches in the active area **320** and the wide etched region at the deeper level for the termination area **321**.

FIG. 4G illustrates an exemplary structure with the masked pattern for the guard rings in the termination area **321**, with all the resist cleared from the active area **320**. FIG. 4G illustrates a gate implant. The vertical and tilted p-implants regions around the gate trench **203**, and the shield trench **204** such as implanted regions **206**, **207**, **208**, **209** in the side walls **217a**, **217b**, **218a**, **218b** of the gate trench(es) **203** and shield trench(es) **204** and also P implant **306a** regions (also known as guard ring implants) are then performed, and the resist stripped. In the example, the implants are then activated as described in the previous exemplary process, and a thermal oxide grown to improve surface behavior.

FIG. 4H illustrates an exemplary wafer after deposition of Silicon dioxide (or other dielectric) **307** and etch back with a mask to protect the termination area **321**. FIG. 4H further illustrates passivation and ohmic contact windows. This leaves the dielectric **307** (such as the SiO<sub>2</sub> passivation **307**) over the termination area **321**, while forming spacers **214** (such as the dielectric spacers) in the active area **320** trenches. The mask is referred to as the ohmic contact mask, since it leaves open areas where the silicided contacts will subsequently be formed.

FIG. 4I illustrates an exemplary formation of ohmic contacts. FIG. 4I illustrates the wafer after the deposition of the ohmic contact metal (e.g. Nickel), formation of the silicide by techniques such as appropriate annealing, and removal of the excess metal. As shown in FIG. 4I, ohmic contacts such as gate **211**, source **210**, shield **212** and shield pickup contact regions **501** (FIG. 5A), and drain **213** contacts are formed. In this example, in order to form the drain contact **213** with the same anneal, the backside films are first stripped with the frontside protected by a photoresist, a layer of material such as Nickel is deposited on the back, the protective resist is removed, and then both the top and bottom surfaces are subjected to a single anneal.

FIG. 4J illustrates an exemplary trench fill. As shown in FIG. 4J, the trenches are filled and the structure is planarized with a mask such as trench fill **312** used to preserve thick dielectric **307** over the passivation areas. At this stage, there may be, for example, two options for connecting the shield to source potential.

FIG. 4K illustrates a first exemplary process flow option with shield connected to the source at device edge and source metal overlay. FIG. 4K shows where the connection between the shield and source occurs at the device edge. Both the shallow and deep trench are filled by the same trench fill technique as described elsewhere in this disclosure. In this example, a separate mask is used to etch the trench fill dielectric in a location not shown in the figure, to allow the source overlay metal **313** to connect the shield to the source.

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FIG. 4L illustrates a second exemplary process flow option with shield connected to the source at each unit cell and shield trench metal fill. FIG. 4L shows a different exemplary process where a mask is used to remove the trench fill material from the deeper trenches. In this example, then these trenches are refilled to a metal 414 (or a shield trench fill 414) such as CVD Tungsten, while the gate trenches remain filled with dielectric to ensure gate-source isolation.

FIG. 4M illustrates the second exemplary process flow option with shield connected to the source at each unit cell and metal overlay. In this example, the source overlay metal is then patterned, as shown in FIG. 4M, allowing the formation of shield-source shorts at the unit cell level. It may be also possible to use a mask to simply etch the trench fill and spacer material fully or partially in the deeper trench, so that when the trench is filled during overlay metal deposition, a shield to source short occurs locally in every cell.

FIG. 5A illustrates an exemplary layout technique for trench shield VJFET with common-center-line gate and shield trenches, and shield connected to the source. FIG. 5A shows an exemplary layout technique for the trench shielded VJFET shown and described in connection with, for example, FIGS. 2A and 2B, where the gate and shield trenches have a common center, for the case of a simple stripe layout. The gate trenches 203, shield trenches 204 and source mesa 226 form an active cell array. The guard ring termination area 321 forms a ring around the device active cell array. The details of the individual guard rings within 321 are not shown, but the first guard ring closest to the active area is connected to the source shield potential. The shield pickup 501, for example, is shown at the top of the cell array, where a wide p+ region is formed, and the trench fill dielectric is etched off, so the source overlay metal 313 connects the source mesas to the shield. On the other side of the device, the gate trenches terminate in a wide area where the gate p+ region is formed, and a large area contact is opened, allowing formation of the gate pickup area 502 and the gate pad 503. The gate pad 503 may also have metal overlay in order, for example, to provide wire bonding capabilities. In this example, the gate pickup 502/gate pad region 503 is isolated from the guard ring termination by one or more floating guard rings, appropriately spaced to provide voltage isolation in excess of the gate-source voltage rating of the device.

FIG. 5B illustrates an exemplary layout technique for trench shield VJFET with common-center-line gate and shield trenches, and shield connected to the gate. FIG. 5B shows another exemplary layout technique for the trench shielded VJFET of structure illustrated in FIG. 2B, where the gate and shield trenches have a common center, for the case of a simple stripe layout. The gate trenches 203, shield trenches 204 and source mesa 226 form an active cell array. In this example, the guard ring termination area 321 forms a ring around the device active cell array. The details of the individual guard rings within 321 are not shown, but the first guard ring closest to the active area is connected to the source shield potential. The shield pickup 501, for example, is shown on the same side as the gate pickup 502. In this instance, the shield can be easily shorted to gate potential.

FIG. 5C illustrates an exemplary layout technique for trench shield VJFET without common-center-line gate and shield trenches, and shield connected to the source. FIG. 5C shows an exemplary layout technique for the trench shielded VJFET of structure illustrated in FIG. 2C, where the gate and shield trenches have staggered centerlines 215a, 215b, for the case of a simple stripe layout. The gate trenches 203, shield trenches 204 and source mesa 226 form an active cell array. In this example, the guard ring termination area 321 forms a ring

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around the device active cell array. The details of the individual guard rings within 321 are not shown, but the first guard ring closest to the active area is connected to the source shield potential. The shield pickup 501, for example, is shown at the top of the cell array, where a wide p+ region is formed, and the trench fill dielectric is etched off, so the source overlay metal 313 connects the source mesas to the shield. On the other side of the device, the gate trenches terminate in a wide area where the gate p+ region is formed, and a large area contact is opened, allowing formation of the gate pad 503. This region is isolated from the guard ring termination by one or more floating guard rings, appropriately spaced to provide voltage isolation in excess of the gate-source voltage rating of the device. For a configuration where some shield trench 204 implanted sidewall regions 208 need to be connected to the source, a careful design of the source pickup region 501 and the wafer rotation angles during tilted implantation are needed in order to connect desired implanted sidewall regions 208 to the source potential. For example, by using gate and shield mesas with different length (along direction A) and appropriate wafer rotation angle during implantation, the shadowing effect of neighboring mesas can be removed to allow the implanted shield sidewall regions 208 to connect to the end of the shield trench along direction A. Alternatively, an additional photomask may be used to remove the spacers 214 on some shield trench sidewalls 218a, so that the source contacts 210 metal will also connect to some implanted regions 208.

FIG. 5D illustrates an exemplary layout technique for trench shield VJFET without common-center-line gate and shield trenches, and shield connected to the gate. FIG. 5D shows another exemplary layout technique for the trench shielded VJFET of structure illustrated in FIG. 2C, where the gate and shield trenches do not have a common center, for the case of a simple stripe layout. The gate trenches 203, shield trenches 204 and source mesa 226 form an active cell array. In this example, the guard ring termination area 321 forms a ring around the device active cell array. The details of the individual guard rings within 321 are not shown, but the first guard ring closest to the active area is connected to the source shield potential. The shield pickup 501, for example, is shown on the same side as the gate pickup 502. In this instance, the shield can be easily shorted to gate potential.

FIG. 5E illustrates an exemplary layout technique for trench shield VJFET without common-center-line gate and shield trenches, and shield connected to the source at unit cell level. FIG. 5E shows an alternate cell array, using hexagonal cells. The inner hexagons are the shield trench 204, and allow local shorting between the shield and source overlay metal, using techniques such as the ones described above. The shield trenches are surrounded as shown by the source mesas 226 and gate trenches 203. In this example, the source overlay metal 313 connects the source mesa tops to the shield trenches everywhere in the active area. The cell array is surrounded by the same termination guard ring region 321. The gate pad, for example, is connected to the gate trench array as shown to form the gate pad 503. This type of cell layout can help increase the channel density of the device, allowing for lower on-resistance per unit area when the channel contribution is high, for e.g., in lower voltage devices.

It should be understood that the tilted implantation and wafer rotation during implantation (as needed in the fabrication corresponding to FIGS. 3G and 4G) may need to be carefully designed to avoid implanting the gate and shield mesa sidewalls perpendicular to axis A (in FIG. 5A and FIG. 5C), as not to create a connection between the shield and the gate regions through the mesa sidewalls by completely

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implanting the shield trench sidewall all the way to the bottom of the shield trench, for configurations where the shield needs to be connected to the source potential.

What is claimed:

1. A shielded junction field effect transistors (JFET), the shielded JFET comprising:
  - a source contact,
  - a channel area of a first conductivity type disposed below the source electrode along a first direction, the channel area comprising one or more planar layers of the first conductivity type, the channel area having an upper planar surface and a lower planar surface spaced apart along the first direction;
  - a first trench, the first trench having:
    - a first bottom surface located in between the upper planar surface and the lower planar surface along the first direction, the first bottom surface extending along the first direction,
    - a first depth that extends a first distance into the channel area from the upper planar surface of the channel layer towards the first bottom surface along the first direction,
    - a first center line,
    - a first pair of side walls spaced apart from one another along a second direction that is perpendicular to the first direction, the first pair of side walls extending from the first bottom surface of the first trench to the upper planar surface of the channel area;
  - a first implanted U-shaped conductivity region of the second conductivity type in the channel area comprising:
    - (1) a first portion extending along the bottom surface of the first trench; and (2) a second portion extending from the first bottom surface of the first trench to the upper planar surface of the channel area along each of the pair of side walls; and
  - a gate contact disposed in the first trench and adjacent to the first bottom surface of the first trench; and
  - a second trench, the second trench having:
    - a second bottom surface located in between the upper planar surface and the lower planar surface along the first direction, the first bottom surface extending along the first direction,
    - a second depth that extends a second distance into the channel area from the upper planar surface of the channel layer towards the second bottom surface along the first direction, the second depth being greater than the first depth;
    - a second center line,
    - a second pair of side walls spaced apart from one another along the second direction, the second pair of side walls extending (1) from the second bottom surface of the first trench towards the upper planar surface of the channel area and (2) at least partially between the second bottom surface of the second trench and the upper planar surface of the channel area;
    - a second implanted U-shaped conductivity region of the second conductivity type in the channel area comprising: (1) a first portion extending along the second bottom surface of the second U-shaped trench; (2) a second portion extending at least partially between the second bottom surface of the second trench and the upper planar surface of the channel area along each of the second pair of side walls; and
    - a shield contact disposed adjacent to the second bottom surface of the second trench.
2. The shielded JFET of claim 1, wherein the shield contact is electrically connected to the source contact so as to hold the shield contact at source potential.

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3. The shielded JFET of claim 1, wherein the shield contact is electrically connected to the gate contact so as to hold the shield contact at gate potential.

4. The shielded JFET of any of claims 1-3, further comprising:

a first unimplanted region extending along each of the pair of side walls of the second trench, the first unimplanted portion being disposed between the second bottom surface and the second portion of the second U-shaped conductivity regions of the second trench along the first direction.

5. The shielded JFET of claim 1, wherein the second portion of the second U-shaped conductivity region of the second trench extends from the second bottom surface of the second trench along the entire length of the second pair of side walls in the first direction.

6. The shielded JFET of claim 1, wherein the first centerline is fully aligned with the second centerline.

7. The shielded JFET of claim 1, wherein the second pair of side walls extend between the first bottom surface of the first trench and the second bottom surface of the second trench along the first direction.

8. The shielded JFET of claim 1, wherein the first centerline is spaced a third distance from the second centerline along the second direction.

9. The shielded JFET of claim 1, wherein the first centerline is spaced a fourth distance from the second centerline along the second direction such that the first trench is separate from the second trench.

10. A method of creating a shielded JFET, the method comprising:

forming a channel area of a first conductivity type disposed below the source electrode along a first direction, the channel area comprising one or more planar layers of the first conductivity type, the channel area having an upper planar surface and a lower planar surface spaced apart along the first direction;

forming a source contact above the channel area along a first direction,

forming a first trench, the first trench having:

a first bottom surface located in between the upper planar surface and the lower planar surface along the first direction, the first bottom surface extending along the first direction,

a first depth that extends a first distance into the channel area from the upper planar surface of the channel layer towards the first bottom surface along the first direction, a first center line,

a first pair of side walls spaced apart from one another along a second direction that is perpendicular to the first direction, the first pair of side walls extending from the first bottom surface of the first trench to the upper planar surface of the channel area;

forming a first implanted U-shaped conductivity region of the second conductivity type in the channel area comprising: (1) a first portion extending along the bottom surface of the first trench; and (2) a second portion extending from the first bottom surface of the first trench to the upper planar surface of the channel area along each of the pair of side walls; and

forming a gate contact disposed in the first trench and adjacent to the first bottom surface of the first trench; and forming a second trench, the second trench having:

a second bottom surface located in between the upper planar surface and the lower planar surface along the first direction, the first bottom surface extending along the first direction,

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a second depth that extends a second distance into the channel area from the upper planar surface of the channel layer towards the second bottom surface along the first direction, the second depth being greater than the first depth;

a second center line,

a second pair of side walls spaced apart from one another along the second direction, the second pair of side walls extending (1) from the second bottom surface of the first trench towards the upper planar surface of the channel area and (2) at least partially between the second bottom surface of the second trench and the upper planar surface of the channel area;

forming a second implanted U-shaped conductivity region of the second conductivity type in the channel area comprising: (1) a first portion extending along the second bottom surface of the second U-shaped trench; (2) a second portion extending at least partially between the second bottom surface of the second trench and the upper planar surface of the channel area along each of the second pair of side walls; and forming a shield contact disposed adjacent to the second bottom surface of the second trench.

11. The method of claim 10, wherein the shield contact is electrically connected to the source contact so as to hold the shield contact at source potential.

12. The method of claim 10, wherein the shield contact is electrically connected to the gate contact so as to hold the shield contact at gate potential.

13. The method of claim 10, wherein the second portion of the second U-shaped conductivity region of the second trench extends from the second bottom surface of the second trench along the entire length of the second pair of side walls in the first direction.

14. The method of claim 10, wherein the first centerline is fully aligned with the second centerline.

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15. The method of claim 10, wherein the second pair of side walls extend between the first bottom surface of the first trench and the second bottom surface of the second trench along the first direction.

16. The method of claim 10, wherein the first centerline is spaced a third distance from the second centerline along the second direction.

17. The method of claim 10, wherein the first centerline is spaced a fourth distance from the second centerline along the second direction such that the first trench is separate from the second trench.

18. The method of claim 10, further comprising:

preventing ion implantation in a first unimplanted region extending along each of the second pair of side walls of the second trench, the first unimplanted portion being disposed between the second bottom surface and the second portion of the second U-shaped conductivity regions of the second trench along the first direction.

19. The method of claim 18, wherein the step of preventing further includes depositing a dielectric on each of the second pair of side walls adjacent to the first unimplanted region.

20. The method of claim 18, wherein the step of preventing further includes performing thermo oxidation.

21. The method of claim 14, further comprising:

preventing ion implantation in a first unimplanted region extending along each of the second pair of side walls of the second trench, the first unimplanted portion being disposed between the second bottom surface and the second portion of the second U-shaped conductivity regions of the second trench along the first direction.

22. The method of claim 21, wherein the step of preventing further includes depositing a dielectric on each of the second pair of side walls adjacent to the first unimplanted region.

23. The method of claim 21, wherein the step of preventing further includes performing thermo oxidation.

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